THE UNIVERSITY OF ALBERTA

DETERMINATION OF SERVICE FACILITY REQUIREMENTS OF A RADIOLOGY DEPARTMENT AT A DESIRED PERFORMANCE LEVEL

by

© ROBIN LIM

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

OF MASTER OF BUSINESS ADMINISTRATION

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled DETERMINATION OF SERVICE FACILITY REQUIREMENTS OF A RADIOLOGY DEPARTMENT AT A DESIRED PERFORMANCE LEVEL submitted by ROBIN LIM in partial fulfilment of the requirements for the degree of Master of Business Administration.

ABSTRACT

The problem of congestion is not an unusual phenomenon in the hospital. At the Radiology Department, University of Alberta Hospital, many patients arrive without notification; consequently, they usually have to wait for a considerable length of time before they are x-rayed.

The purpose of this study is to determine the number of x-ray rooms to be provided in order to achieve a desired level of performance. The desired level of performance is a reasonable balance between patients' waiting time and technicians' idle time. The study is confined to non-scheduled patients.

A simulated model of the department was constructed using the General Purpose Simulation System/360. The simulation was successful. The changes in waiting time before examination as a result of changes in the provision of service capacity were analyzed. The results of the investigation showed that three x-ray rooms should be provided at the Radiology Department in order to achieve the desired performance level.

ACKNOWLEDGEMENTS

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The writer is also grateful to Mr. R. C. Chamberlain, Head of the Work Study Department, U. of A. Hospital, for initiating this study and for his many suggestions.

Finally, thanks are extended to Dr. F. McConnell, Director of the Radiology Department, U. of A. Hospital, and members of his staff for their cooperation in making this study possible.

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CHAPTER I

INTRODUCTION

Industrial engineering and operations research have received increasing attention in hospital administration over the last decade. The increase of full time staff specialists, professional consultants, and academicians in hospital industrial engineering has been significant (Smalley and Freeman, 1966. p. 15). In England, perhaps more than anywhere, research has been carried out very extensively by the Organization and Methods section of the Ministry of Health. In America, the Committee on Methods Improvement of the American Hospital Association has also made significant contributions. The American Institute of Industrial Engineers also created a Hospital Division in 1964 in recognition to the increasing interest shown in this field (Smalley and Freeman, 1966, pp. 14-15).

Studies on waiting lines have been carried out quite extensively at the outpatient department. Several types of appointment system have been suggested in attempts to reduce patients' waiting time and to maintain a low level of physicians' idle time. The problem of queuing also arises at radiology departments where patients arriving for service are delayed prior to being served.

Waiting line problems are concerned with the design and planning of facilities to meet a fluctuating demand for services. If

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service facilities are inadequate to meet the demand, this causes congestion to occur at the service facility and incurs certain associated costs. However, increased service capacity to reduce congestion usually caused increased idleness in the service system, thus incurring a cost of idle service facilities. In most industrial situations, we strive to design systems that balance the aggregate costs of idleness and congestion and minimize the total cost of the service system. However, in the hospital situation, it is difficult to associate patients' waiting time with cost. But the knowledge gained from operations research and hospital industrial engineering can still provide hospital administrators enough information as a basis for operating decisions. Among the actions that might be taken at a radiology department in order to change the properties of the queuing system are to change the number of service facilities, change the average service time, or change the arrival pattern. This study deals with service facility requirements.

Waiting line problems can be solved by the use of analytical or simulation technique. Figure 1 (Hillier and Lieberman, 1967. p. 287) shows the elements of a queuing process; namely, input source, queue, service facilities, and queue discipline.

For the problem at hand, the input source (or patient) is characterized by its size, arrival distribution and the attitude of the patients. The queue in this case is the patients waiting for service. The service facilities are characterized by their

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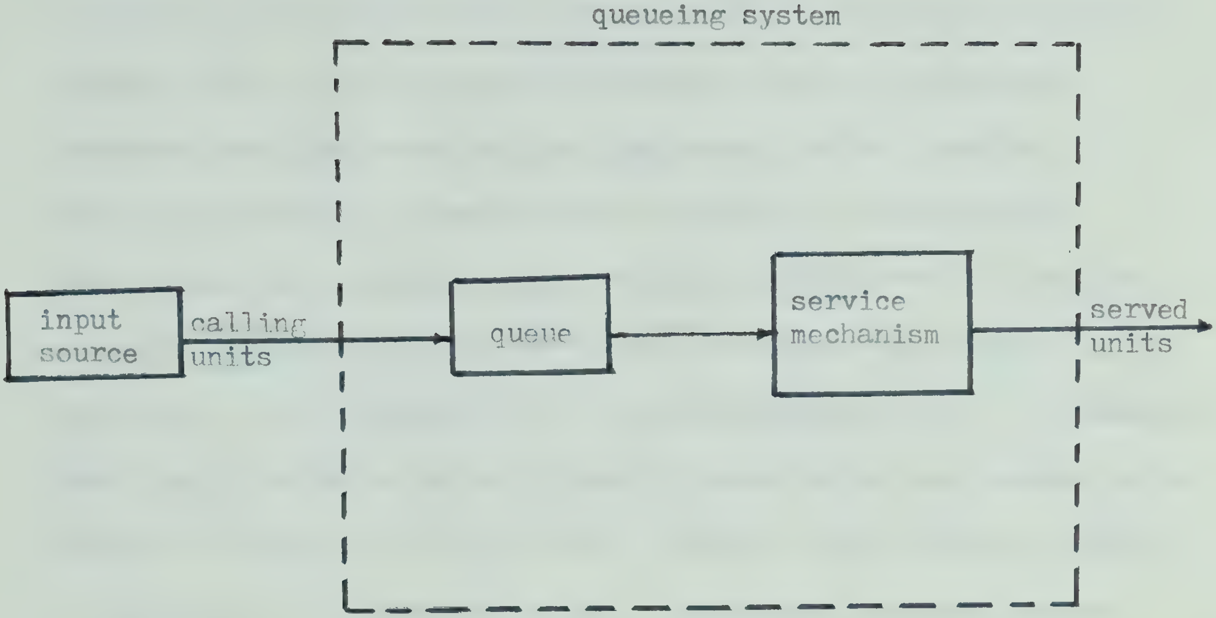

FIGURE 1. THE BASIC QUEUEING PROCESS.

arrangements and distribution of service time. Queue discipline refers to the manner in which the patients are served.

Although analytical techniques are very useful, a perusal of the literature in queuing theory nevertheless shows that only relatively simple problems can be solved by this method. Analytical techniques are, in general, most suitable for queues that have settled down to a steady state.

For more complex problems, simulation offers an alternative (Hillier and Lieberman, 1967. p. 317). Simulation means different things to different people, but it is broadly accepted as "the act of representing some aspects of the real world by numbers

or symbols which may be easily manipulated to facilitate the study" (McLeod, 1968. p. 5). This technique has become increasingly important with the advent of the high speed digital computer. The many varieties of examinations conducted at the radiology department, the uncertain nature of the input pattern and service pattern, and the complexity of patient flow made the problem difficult, if not impossible, to analyze mathematically. A simulated model would be easier to manipulate if experiments were conducted to observe the behavior of the system. Further, more variables could be considered in a simulated model. The General Purpose System Simulator (GPSS) is one of a variety of programming languages designed for modeling queuing systems. This language is used for this study.

The various aspects of the study under investigation are discussed in chapter two. Included in that chapter are the statement of the problem, description of the system, limitations of the study, statement of assumptions, and definition of terms. Chapter three presents a review of related literature pertinent to the study. The fourth chapter deals with procedures and research design. The fifth chapter deals with the model, and the last chapter deals with the findings.

CHAPTER II

PROBLEM FORMULATION

STATEMENT OF THE PROBLEM

The major objective of this study was to find the number of x-ray rooms required for the existing load of non-scheduled patients arriving at the Radiology Department, University of Alberta Hospital.

Basically there are two kinds of patient arriving at the department: scheduled and non-scheduled. Non-scheduled patients arrive at random. This causes difficulties in estimating the demand of workloads. If facilities were insufficient, this may result in considerable waiting especially during busy periods.

Fetter and Thompson suggested that an acceptable solution to the provision of service facility in an outpatient department is a "balance" between patients' waiting time and doctors' idle time (1966, p. 66). Welch and Bailey pointed out that a doctor's time is not infinitely more valuable than the patient's. They pointed out that providing a minimum number of service facility is undesirable on "humanitarian ground" and it represents a "loss of working time which the country can ill afford." (1952, p. 1105).

Our purpose is to provide enough x-ray rooms so that a

reasonable balance between patients' waiting time and technicians' idle time is achieved. Among several people interviewed, the opinion seems that a "reasonable balance" should provide a performance level such that approximately 80 percent of all patients should not wait for more than 10 minutes before the x-ray examination. It is uncertain whether this policy provides a reasonable balance of technicians' time. The policy will only be acceptable if the technician is occupied approximately 80 percent of the total working time.

The above criteria should also be compared with alternative performances when a different service capacity is provided.

DESCRIPTION OF THE RADIOLOGY DEPARTMENT

This section gives a description of the operation of the radiology department. It provides the necessary background before the assumptions and limitations of the study are dealt with.

The work of the department is to provide radiological examinations of patients at the request of referring doctors and to report the radiologist's findings to the referring doctors.

The patients may be referred from several sources including (i) those who are admitted into the hospital as inpatients, (ii) visitors from the Outpatient Department, (iii) cases from the Emergency Department, (iv) university students from the Student Health

[illegible]

Services, and (v) annual chest x-ray of hospital employees.

The patients arrive at the department either as scheduled or non-scheduled patients. Scheduled patients may require dietary preparations. Scheduled examinations include barium meal, barium enema, cardiac fluroscopy, gall bladder, heart catheterization, etc. Such examinations are called "special examinations." Non-scheduled patients are those requiring general radiographic examinations which include x-ray for skull, chest, abdomen, spine, etc. Such examinations are referred to as "general examinations."

All general examinations are conducted at either Rooms 1, 2, or 7. Room 2 is opened only in the afternoon from 1:00 p.m. onwards because it is used for gall bladder examination in the morning. Chest x-ray is conducted at Room 13. Figure 2 shows the location of the x-ray rooms in the department.

Special examinations require special equipment. Rooms set aside for this purpose include Room 3 (barium follow-up), Room 4 (neuro vascular and tomography), Room 5 (heart catheterization and radiology vascular priority), Room 6 (barium meal), Room 8 (barium enemas, myelograms, salpingograms, gall bladder fluoroscopy), Room 9 (barium enemas, cardiac fluoroscopy, and I.V.P.).

The department also provides a mobile x-ray machine in cases where the patients are too ill to be moved. The mobile machine allows the x-ray to be made in the patient's ward.

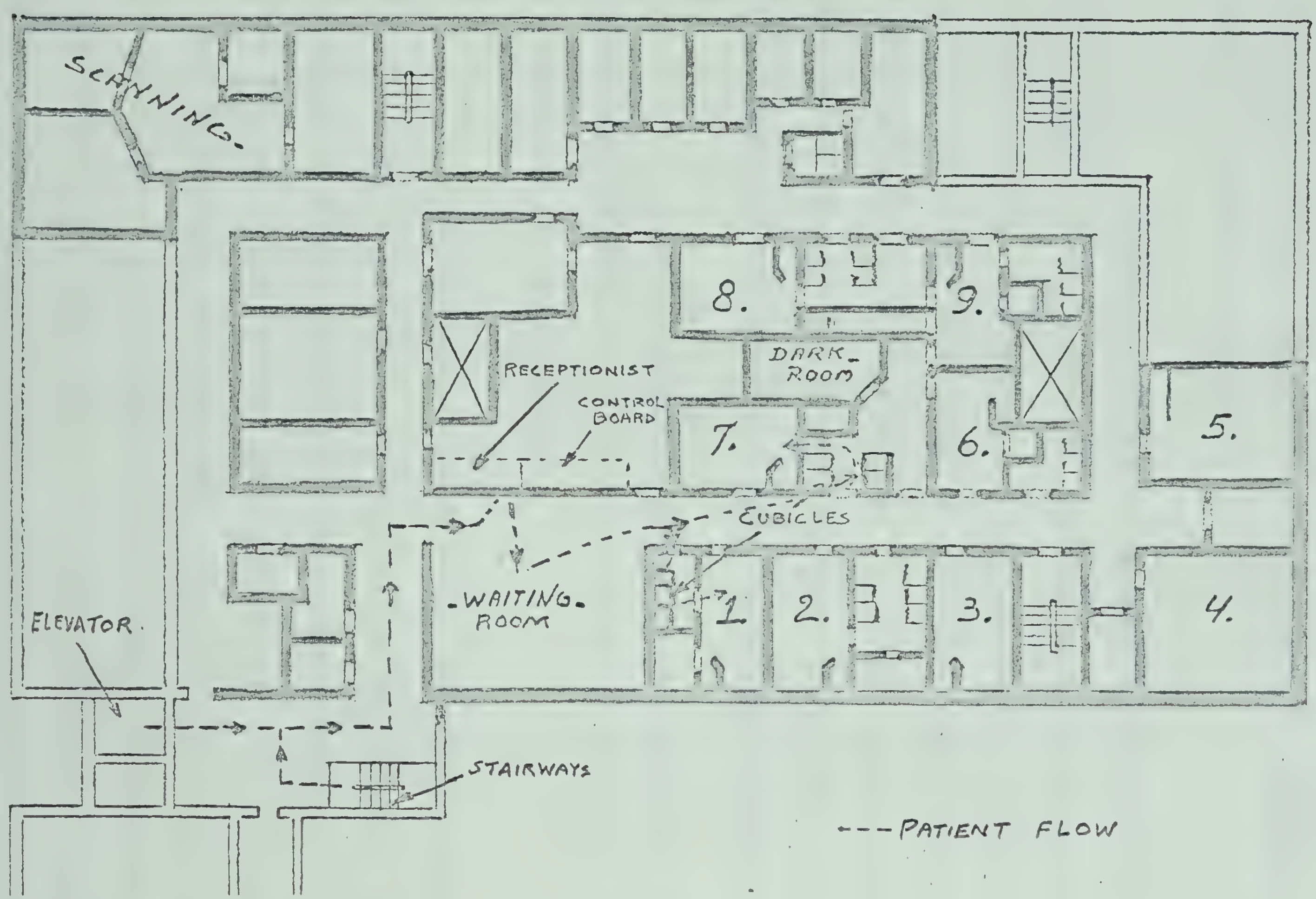

FIGURE 2. TOP VIEW OF THE RADIOLOGY DEPARTMENT

In order to have a radiographic examination the referring doctor must first fill out a three-part requisition Form U.H. 41 shown in Figure 3.

Patients from the Outpatient Department and the Student Health Services have to take the requisition to the x-ray department on the day of the examination. If the examination is "special", the referring doctor or a member of his clinic has to telephone the x-ray department for an appointment. On receiving the call, the receptionist consults the Appointment Sheet to see what day is available and advises the caller when the patient has been scheduled.

Cases of emergency arrive at the department without notification and they are given first priority. All others are served on a first-come-first-served basis.

All patients arriving at the department must first visit the receptionist before waiting at the Waiting Room. The receptionist enquires whether the patient has previously been x-rayed at the hospital. This enables the department to find out the location of previous records. The receptionist also completes the requisition (e.g. enter amount to be charged) and prepares a film-marker card. If the patient is an inpatient, the film is marked and catalogued according to the hospital number assigned to him when he was admitted. However, if he is an outpatient, the receptionist assigns an unused number from a numerically-controlled register. This serial number is given until such time, if ever, the patient is admitted into the

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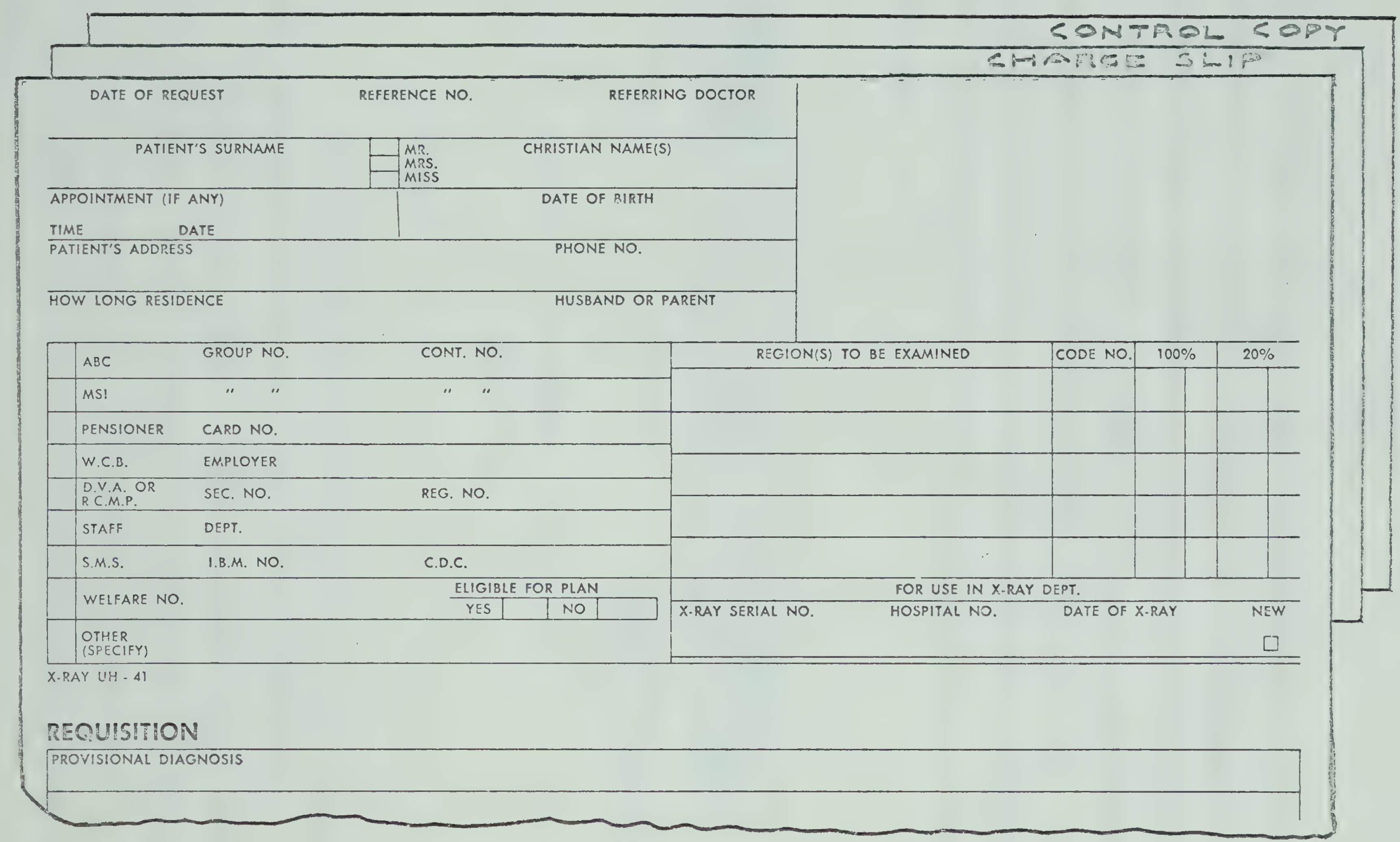
CONTROL COPY
CHARGE SLIP
DATE OF REQUEST
REFERENCE NO.
REFERRING DOCTOR
PATIENT'S SURNAME
MR.
MRS.
MISS
CHRISTIAN NAME(S)
APPOINTMENT (IF ANY)
TIME
DATE
DATE OF BIRTH
PATIENT'S ADDRESS
PHONE NO.
HOW LONG RESIDENCE
HUSBAND OR PARENT
ABC
GROUP NO.
CONT. NO.
MSI
" "
" "
PENSIONER
CARD NO.
W.C.B.
EMPLOYER
D.V.A. OR R.C.M.P.
SEC. NO.
REG. NO.
STAFF
DEPT.
S.M.S.
I.B.M. NO.
C.D.C.
WELFARE NO.
ELIGIBLE FOR PLAN
YES
NO
OTHER (SPECIFY)
REGION(S) TO BE EXAMINED
CODE NO.
100%
20%
FOR USE IN X-RAY DEPT.
X-RAY SERIAL NO.
HOSPITAL NO.
DATE OF X-RAY
NEW
X-RAY UH - 41
REQUISITION
PROVISIONAL DIAGNOSIS

FIGURE 3. A REQUISITION

hospital. If this occurs, the hospital number supersedes the given serial number. If the patient has never visited the department in the past, the receptionist also types an index strip shown in Figure 4. This strip is maintained in alphabetical order on a frame mounted on a wall bracket near the reception counter. This enables the receptionist to locate a serial number or hospital number during future visits. After preparing the documents, she passes them to the Control Board Section.

Doe, John	1945	X123456
Doh, Pete	1950	X112112 499999
Ee. Jack	1964	123333
Name	Birthdate	Hospital no. and/or serial no. (prefix X)

FIGURE 4

INDEX STRIP

The "heart" of the department is at the Control Board. The board displays the control copy (copy 3) of the requisition to reflect the progress of the patients through the various stages of the examination process. The following stages are identified (i) waiting (ii) control (or examination) (iii) film control (iv) dismissed. By looking at the control board, the control clerk knows when to call the next patient.

When a room is available (scheduled or non-scheduled) the control clerk inserts the control copy of the requisition in the appropriate slot of the board and passes the remainder of the requisition to a nurse or a technician to call the patient for the x-ray. An outpatient may be required to put on a white hospital gown at any cubicle nearest to the assigned room. After dressing, he waits outside the cubicles until the technician calls for him. An inpatient is normally in hospital gown already.

The technologist directs the patient to whatever position that is necessary for the x-ray as specified in the requisition. More than one type of examinations may be needed. Further, for each type of examination (e.g. sinuses) more than one x-ray are usually required. Upon completion of the examination, the patient waits at the Waiting Room for his films to be processed and checked.

Meanwhile, the quality control technician picks up the requisition and places it together with the film when it comes out of the O-xmat machine. If the quality of the film is satisfactory, the package goes to a sorting table for further actions and the patient is dismissed. However, if the quality is unsatisfactory, the quality technician will inform the control clerk to arrange for a re-x-ray. Patients who require re-x-rays have priority over other patients except cases of emergency.

A patient who is officially dismissed may require a porter (there are five porters in the department) if he cannot walk. This requires additional waiting.

The present operation of the department is mainly the result of a study undertaken by Woods, Gordon Management Consultants in 1965.

Garland (1962, p. 312) summarizes the operation of a radiology department very appropriately in a form of a summary chart. The summary is shown in Figure 5 with a few modifications in order to portray a summary of the radiology department under investigation.

LIMITATIONS OF THE STUDY

Scheduled patients admitted to Rooms 3, 4, 5, 6, 8, and 9 are controlled by an appointment system based on the average service time. The existence of an appointment system minimizes the waiting time of scheduled patients. Non-scheduled patients arrive without notification and they usually have to wait for a considerable length of time. This study, therefore, is restricted to non-scheduled patients who arrive for general radiographic examinations. In effect, it considers patients admitted to Rooms 1, 2, and 7.*

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* Although chest x-ray is considered as general radiographic examination, it is not included because Room 13 has been set aside specifically for this purpose.

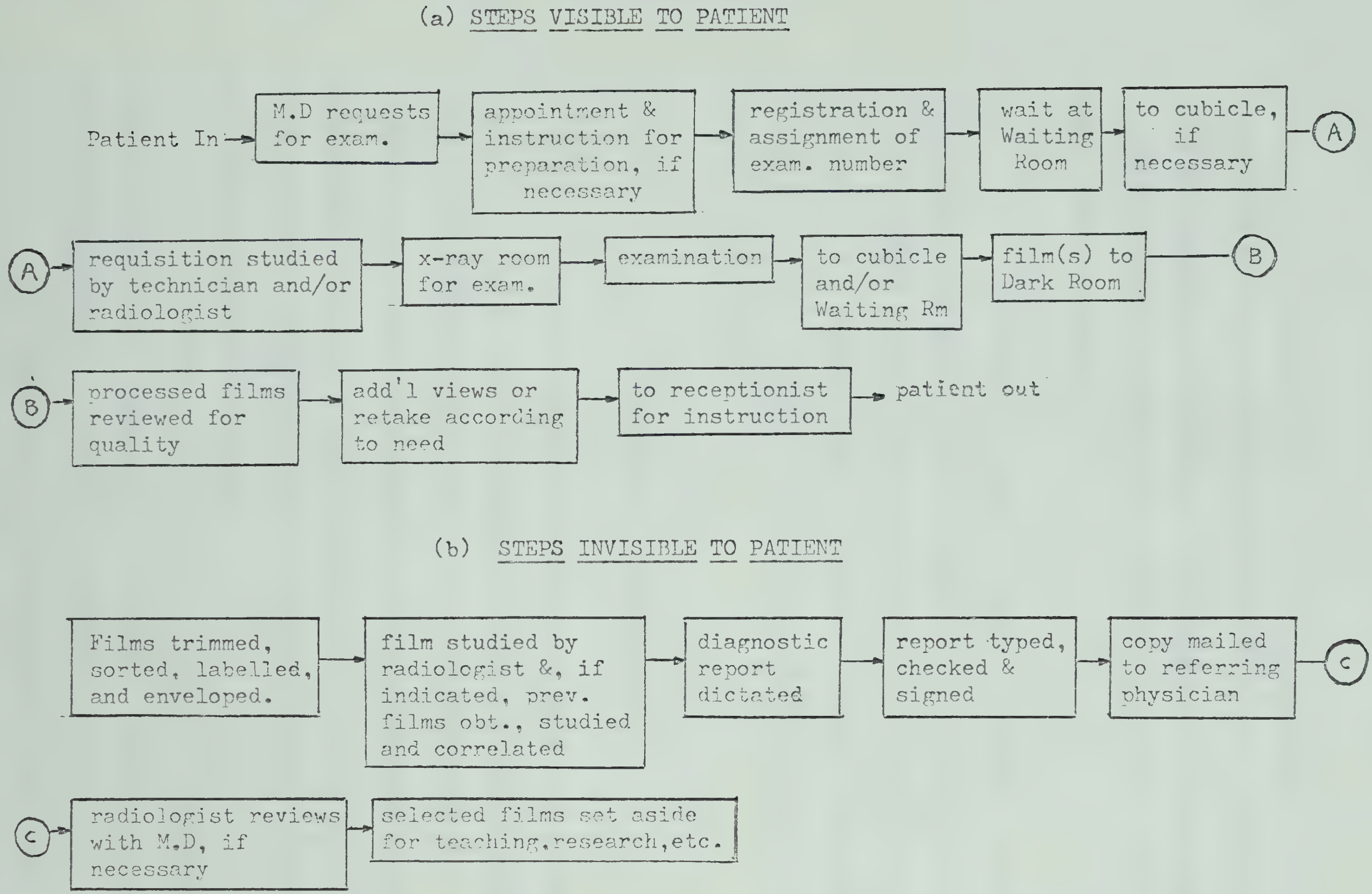

FIGURE 5. SUMMARY CHART OF THE RADIOLOGY DEPARTMENT

The sample was taken from the department for two weeks only (April 21 to May 3) from 8:00 a.m. to 4:00 p.m. By coincidence, there were exactly 500 arrivals. It is assumed that this sample is an adequate representation of the population. No doubt, a larger sample could be taken.

Although the study is limited to service facility requirements, the model to be developed could be used to study changes in the operation of the department. With little or no alteration to the model, the following could be studied: physical alterations and innovations, future changes in workload, personnel changes, policy changes, and the like.

STATEMENT OF ASSUMPTIONS

The following assumptions were made in the study.

1. All x-ray technicians have the same amount of experience. Service time depends upon the experience of the technician, but this consideration is difficult because service time also depends upon the co-operation of the patients. The co-operation of a patient is a function of his personality, his state of health, his age, and his ability to walk.

2. When a long queue is observed, the technicians may have the tendency of "speeding up" their work. The reverse may be true at a less busy period. This is not considered in the study.

3. Patients do not turn away when they notice a

lengthy queue.

4. Enough space at the Waiting Room is assumed. The Waiting Room is shared between scheduled and non-scheduled patients. Since this study deals only with non-scheduled patients, we would expect a lower utilization of the Waiting Room compared to reality. The maximum capacity of the Waiting Room is 20 patients.

5. It is assumed that there is no difference between waiting at the Waiting Room and waiting outside the cubicles. The sum of waiting time at these two places are considered as "waiting time before examination". Consequently, the cubicles are not considered in the model to be developed. This assumption does not significantly affect the performance of the simulated system because patients (already changed to hospital gowns) are normally seen waiting outside the cubicles. If the technicians have to wait for the patients to undress, then the cubicles should be considered as separate facilities. In the department, Room 1 has 3 cubicles, Room 7 has 4 cubicles, and Room 2 has $2\frac{1}{2}$ cubicles.*

6. It is assumed that the time spent at the reception counter is negligible. Since we are interested in waiting time before the examination starts, we can imagine the reception counter as a starting point where arrivals are generated.

7. Machine breakdown and employee absenteeism are not considered.

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* There are 5 cubicles to be shared between Room 2 and Room 3. See Figure 2.

DEFINITION OF TERMS

Outpatients. Patients who are not admitted into the hospital. In this study, this includes patients from the Emergency Department, Outpatient Department, Student Health Services, and employees of the hospital.

Radiologist. A physician who has had specialized training in the use of radiant energy for treatment and diagnosis; this includes x-rays, radium, etc.

Technician. A person skilled in x-ray techniques.

Examination Room/X-ray Room/Service Facility. A room equipped and used for carrying out x-ray examinations. Every room has a technician and a student trainee.

X-ray Examination. The positioning of a patient and the use of x-ray to produce one or more radiographs of a part of the body or a bodily function.

Examination Types. Classification of x-ray examination based upon different roentgenologic methods and the location of the bones. In this study, there are seven "types" identified for non-scheduled patients - e.g. upper extremities, skull, vertebral column, etc. See page 45.

General Radiographic Examination (non-scheduled). X-ray

examination in which dietary preparation is not required and patients do not need an appointment. Each of the seven examination types is considered as a general radiographic examination. All general radiographic examinations can be performed by the same equipment with very little adjustment - i.e. at either Room 1, 2, or 7.

Special Radiographic Examination (scheduled). X-ray examination which may require dietary preparation and the patient needs an appointment. Includes enemas, heart catheterization, cardiac fluoroscopy, etc. Each of these has to be performed in a separate room because special equipment is required.

Upper Extremities. The upper part of the body consisting of four main segments: the shoulder girdle, arm, forearm, and hand.

Lower Extremities. The lower part of the body consisting of three main segments: thigh, leg, and foot.

Vertebral Column. Located at the midline in the posterior region of the body, and it consists of a series of bones.

Facial Bones. These are bones which are responsible for the shape and appearance of the face. There are fourteen such bones.

Sinuses. These are air cavities in the skull opening to the nasal cavities.

Mastoid. The mastoid portion forms the prominence of

bone behind the ear known as the mastoid process; it is absent in the newborn but will develop by the fifth year.

Pelvis. A basin-shaped ring of bone at the inferior extremity of the trunk supporting the column and resting upon the lower extremities.

Pelvimetry. A radiographic method of measurement of the size of the bony pelvis. Employed to determine the possibility of normal delivery or necessitate surgical intervention.

CHAPTER III

REVIEW OF RELATED LITERATURE

Useful improvements have been made at the radiology department which have since found their way to many hospitals. Broadly, the interest has centered about information flow (Staggs, 1968; Woods, Gordon Management Consultant, 1965; Fordham, 1968; King and Markewitz, 1958; Wren, 1951); facilities design and space utilization (Copestake, 1967; Towards a Clearer View ..., 1962; Roberts, 1956; Bridgman, 1953); planning and organizing (Ashworth, 1968; Graham, 1968; Copestake, 1967; High, 1965; Starkweather and Mahoney, 1963; Towards a Clearer View ..., 1962; Racie, 1960; Roberts, 1956); and improving work methods (Ashworth, 1961).

Studies on waiting lines have been considered by Kanon (1967), Hansen and Sinder (1964). They showed that the waiting time at the radiology department could be improved if a "flexible" scheduling system were adopted for "special" patients. The approach, however, did not utilize operations research techniques.

However, the problem of queuing has been studied quite extensively at the outpatient department. An early study was made in England by Welch and Bailey (Welch and Bailey, 1952; Bailey, 1952). After considering fifty hypothetical clinics using queuing theory, they produced what is known as an individual appointment system: Schedule

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

two patients when the session begins and schedule every patient at an interval equivalent to the physician's average service time.

White and Pike (1964) used a computer and was able to consider patients' unpunctuality in his model. He devised a block appointment system: Divide the day into approximately 10 blocks and schedule 2 or 3 patients at the beginning of each block.

Fetter and Thompson (1966) of Yale University used a computer simulation to study the variations in patients' waiting time and physicians' idle time by manipulating seven variables: appointment interval, service time, patients' arrival pattern, number of no-shows, number of walk-ins, physicians' arrival pattern, and interruptions in patient services. Fetter and Thompson (1965) also constructed appointment systems and studied their effect on patients' waiting time. Other similar studies at the outpatient department include Jackson (1964) and Katz (1969).

At the delivery suite, John Thompson, Avant and Spiker (1960) of Yale University used queuing theory to evaluate the adequacy of staff and facilities. The nature of the work in this department requires sufficient facilities to avoid or minimize queuing. At a 98 percent probability that arrivals could be satisfied without waiting, they suggested that eight labor rooms, two delivery rooms, and three recovery beds should be provided at the Grace New Haven Community Hospital. The data collected suggests that the average number of patients in the delivery suite conforms to the Poisson distribution.

Whitston (1965) of the University of Southern California used queuing theory to solve the problem of staffing an operating room. He was able to calculate the cost associated with anesthetists' idle time and ancillary staffs' idle time. In order to minimize cost, he suggested that the operating room under investigation should be staffed with three teams of ancillary workers.

Hudson (Smalley and Freeman, 1966. pp. 351 - 355) was concerned with staffing pharmacists at the central pharmacy of the University of Iowa Hospital. He wrote a model of the system using the GPSS II language. The interarrival time distribution was "assumed" to be exponential. The service time was uniformly distributed at the first phase (dispensing orders) as well as the second phase (checking orders). With the model he was able to find out the total time to "drain the system" with 2, 3, and 4 pharmacists. He found that the existing policy of assigning three pharmacists was optimum because an additional pharmacist yielded a small reduction in time to "drain the system", but the elimination of one resulted in a disproportionately large increase in time.

CHAPTER IV

PROCEDURES AND RESEARCH DESIGN

SYSTEM DESCRIPTION

The system under investigation can be described in terms of the following elements:

Components

1. The patients
2. X-ray rooms
3. Waiting line

Variables

1. Time between successive patient arrivals
2. Waiting time before examination
3. Number of x-rays required by each patient
4. Total time spent in the department

Parameters

1. The distribution of interarrival time
2. The frequency of each examination-type
3. The frequency of emergencies
4. The frequency of re-x-rays
5. The number of x-ray rooms

Functional Relationship

The waiting time before examination (variable 2) depends upon variables 1 and 3 and parameters 1, 2, 3, 4, and 5.

The simulated model that we shall develop should imitate the real system. Initially, a flow diagram can be used to show the interactions of the elements and the necessary steps and procedures of the real system. Further, it indicates several factors that have yet to be determined in order to define the simulation model.

Figure 7 shows the flow diagram of the system. The symbols are described more completely in Figure 6. These symbols will also be used for the remainder of the thesis.

Rectangle B in Figure 7 generates arrivals. Diamond C decides whether the arrival is an emergency. If it is, the highest priority is assigned to him (rectangle D). Diamond E determines whether a x-ray room is available. If it is available, we assign the room to him as shown in diamond G. Otherwise, he waits at the Waiting Room in triangle F. The service time (rectangle K) depends upon three factors: (1) number of examinations needed, e.g. 1, 2, 3... (2) the type(s) of examination needed, e.g. sinuses, skull, leg, (3) the time selected for each examination-type chosen in (2). Diamonds H, I, J show the above decisions.

On completion of the x-ray, the patient waits at the Waiting Room again while his film is being processed. This is shown in

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

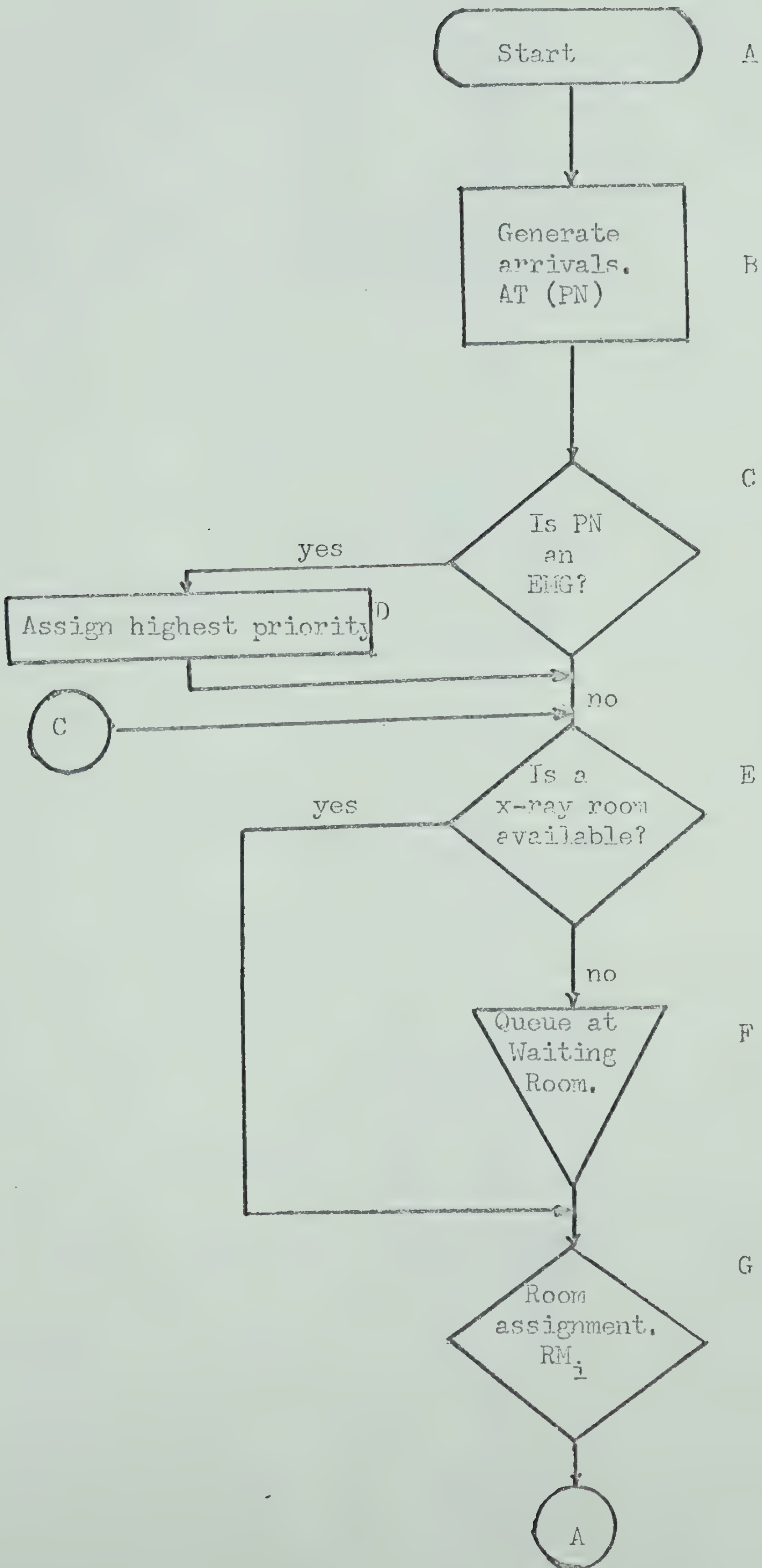
[illegible]

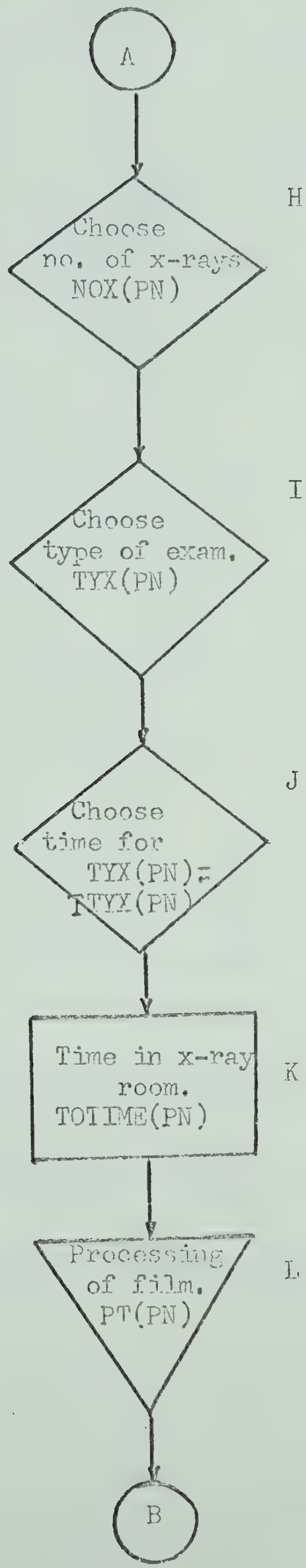
[illegible]

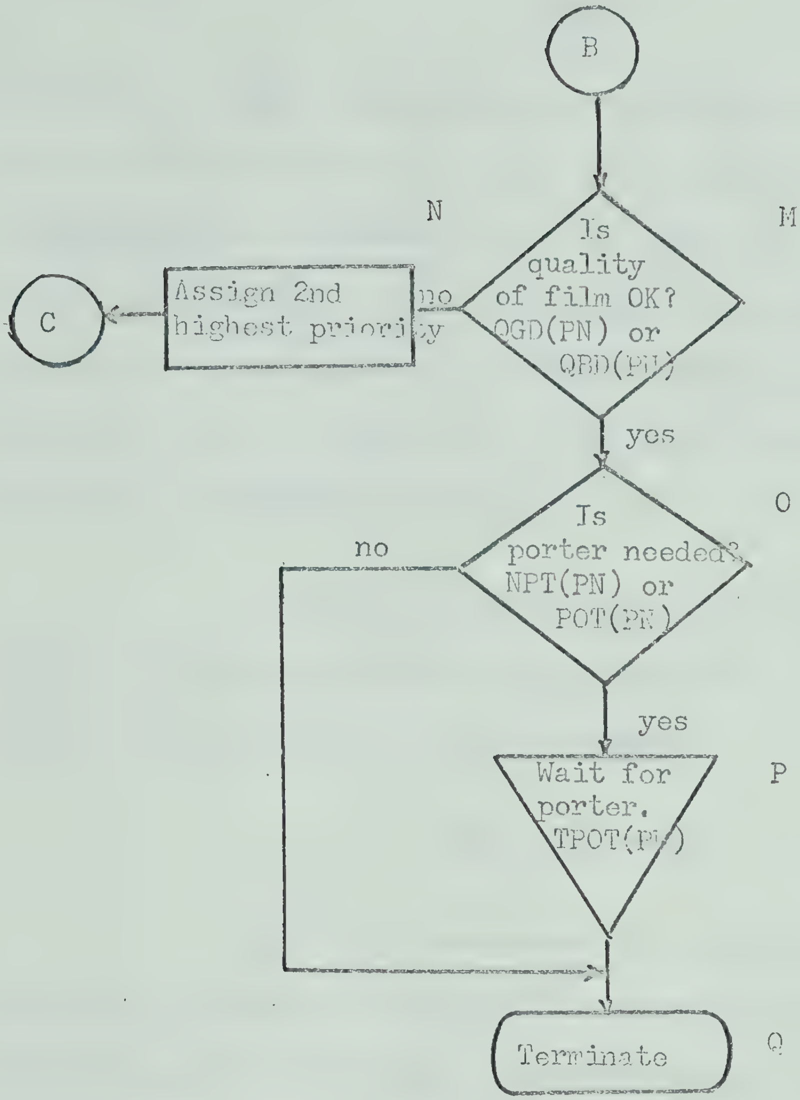
[illegible]

Variables and Index names		Description
Variables:	RN	A newly chosen random number
	PN	Patient number
	AT(PN)	Interarrival time for PNth patient
	QT(PN)	Queuing time of PNth patient before examination (minutes)
	NOX(PN)	Number of examination(s) needed by PNth patient
	TYX(PN)	Types of examination needed by PNth patient
	TTYX(PN)	Time selected for each examination-type chosen by PNth patient
	RMi	Room number 1, 2, ...i
	BEGIN(PN)	Examination time of PNth patient begins
	END(PN)	Examination time of PNth patient ends
	TOTIME(PN)	Total time spent in x-ray room by PNth patient (minutes)
	PT(PN)	Time for processing film of PNth patient (minutes)
	ENDPT(PN)	Processing time of PNth patient ends
	TPOT(PN)	Waiting time for porter by PNth patient
Index names:	EMG	Emergency cases
	NEM	Non-emergency cases
	QGD	Quality of film satisfactory
	QBD	Quality of film unsatisfactory
	POT	PNth patient requires a porter
	NPT	PNth patient does not require a porter

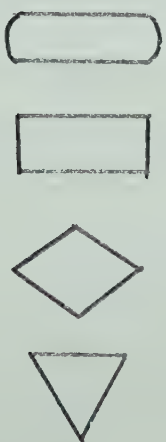
FIGURE 6. VARIABLES AND INDEX NAMES


Start
A
Generate arrivals. AT (PN)
B
Is PN an EMG?
C
yes
Assign highest priority
D
no
C
Is a x-ray room available?
E
yes
no
Queue at Waiting Room.
F
Room assignment. RM_i
G
A


A
Choose no. of x-rays NOX(PN)
H
Choose type of exam. TYX(PN)
I
Choose time for TYX(PN)= TTYX(PN)
J
Time in x-ray room. TOTIME(PN)
K
Processing of film. PT(PN)
L
B



SYMBOL DESCRIPTIONS



Beginning or ending point

Any processing operation except a decision

Decision

Delay

FIGURE 7. FLOW DIAGRAM OF THE SYSTEM.

triangle L. After the waiting period, a decision is made (diamond M) as to whether the quality of the film is satisfactory. If the film is unsatisfactory, the patient has to be re-x-rayed. He is given priority, as shown in rectangle N, over other patients except in cases of emergency. A patient who is officially dismissed has to decide whether he needs a porter (diamond O). If he does, additional waiting may be required as indicated by triangle P.

It should be noted that portering service has no direct affect on the waiting time before examination. It is included here to complete the operation of the department.

COLLECTION OF DATA

Historical data were not sufficient for the study. A method was designed to collect the neccessary data. A Data Collection Form (Figure 8) was clipped to each requisition and the arrival time of the patient was recorded by the receptionist to the nearest minute. The activities of the patient, while he was in the department, were also recorded at various points by the control clerk and the technician. The data were collected for two weeks (April 21 to May 3) from 8:00 a.m. to 4:00 p.m. and 500 observations were made.

ANALYSIS OF DATA

Introduction

From the flow diagram it becomes evident that the following information are required: arrival pattern, service pattern,

Date: ____________________

Source: Ward ____________ OPD ____________

Emerg ____________ Others __________

Time Arrived: ____________

Room Assigned: ____________

Time Assigned: ____________

Exam.-Type: ______________________________

1st / 2nd / 3rd

Time Exam. Starts: ________

Time Exam. Ends: _________

Re-x-ray required? Yes ____ No ____

Time Dismissed: __________

FIGURE 8. DATA COLLECTION FORM

and certain waiting patterns.

Arrival Pattern. From the two weeks' date, the arrival distribution can be determined. However, it is uncertain whether this arrival pattern will remain the same throughout the year. In order to form any definite conclusions, we have to analyze the following : hourly fluctuations of arrival, daily fluctuations of arrival and monthly fluctuations of arrival.

Service Pattern. The flow diagram in Figure 7 shows that when a patient goes into the x-ray room, the following operations take place: (a) choose number of examinations - 1, 2, or 3*, (b) choose the examination-type associated with 1, 2, or 3 examinations chosen in (a), (c) choose the examination time associated with each examination-type selected in (b). In order to do this we have to find out the following : (i) probabilities for (a), (ii) probabilities for (b), (iii) the distribution of x-ray time for each examination-type.

It is uncertain whether the probability of each examination-type varies from day to day. If this happens, it is not possible to attach a probability to each examination-type and the above operations cannot be performed.

It was decided that before embarking into (i), (ii), and (iii), a test should be undertaken to find out whether the probability

* According to the technicians, 4 examinations are rare.

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

of each examination-type varies daily.

Waiting Pattern. This includes the waiting pattern for processing of x-ray film and the waiting pattern for a porter.

Arrival Pattern

Distribution of Time Between Successive Arrivals.

The arrival pattern can be determined by summarizing the "time arrived" column of the Data Collection Form. From the summary of the arrival time, the interarrival time is the difference between successive arrivals. This was done for the two weeks' sample.

The interarrival times for the 500 arrivals were plotted on a histogram (Figure 9). The pattern seems to fit a negative exponential distribution. Consequently, a comparison was made between the actual distribution of the sample with the expected distribution if the arrival does indeed follow an exponential distribution. The result is shown in Table I.

The interarrival times shown in Table I have been divided into eleven classes of three-minute intervals to ease manipulations in calculation. The exponential distribution is given by:

$$f(x) = \frac{1}{\overline{X}} e^{-x/\overline{X}}$$

where $\overline{X}$ is the mean and e is a constant.

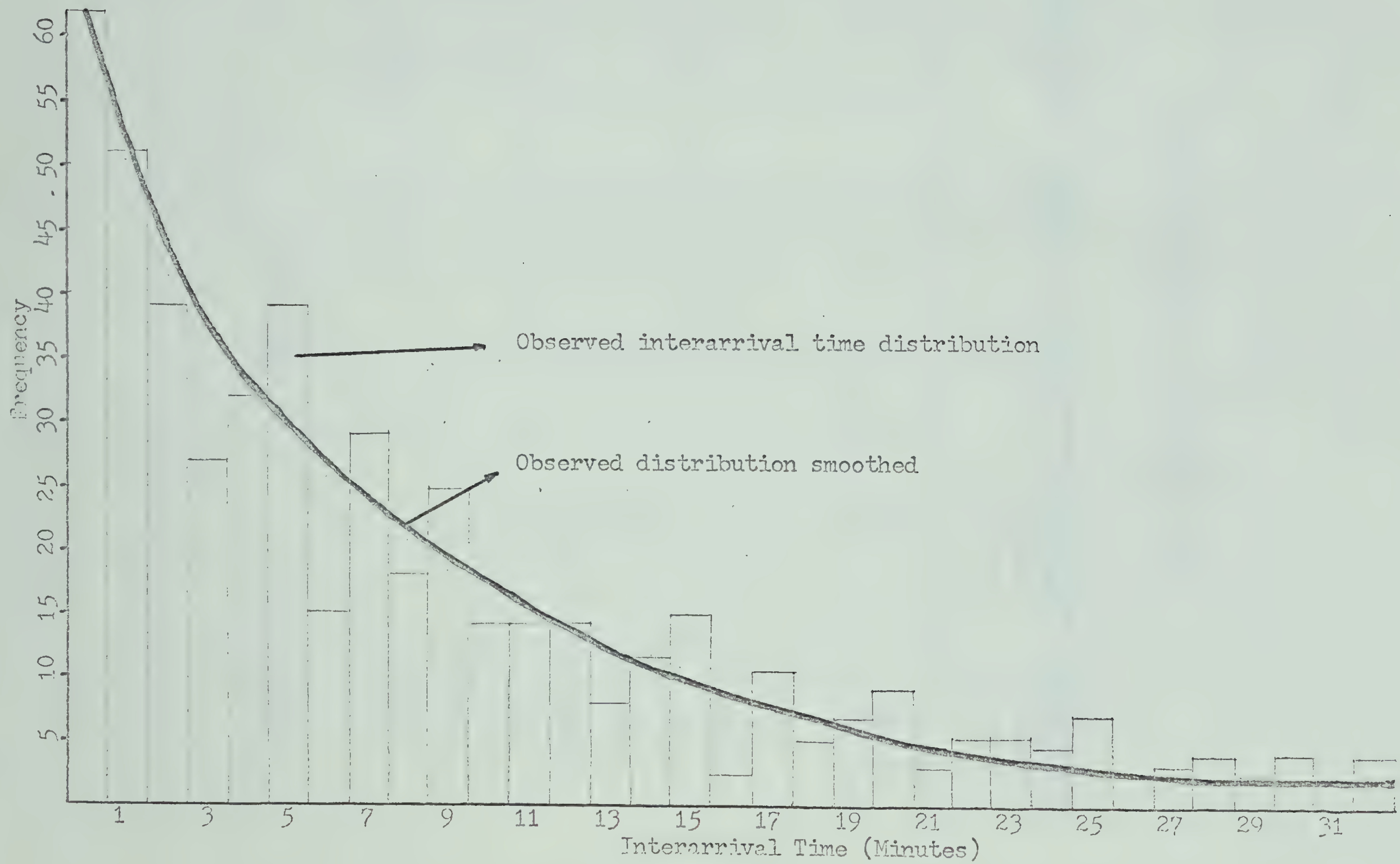


FIGURE 9. INTERARRIVAL TIME DISTRIBUTION

TABLE I

CALCULATION OF TEST STATISTIC FOR
DECISION CONCERNING EXPONENTIAL ARRIVALS

Interarrival time limits X	Mid-points of X	Sample Frequency f_s	Estimated Expected Frequency f_e	Relative Squared Deviation
0.0 - 2.5	1	152	161	.503
2.5 - 5.5	4	98	109	1.110
5.5 - 8.5	7	62	74	1.946
8.5 - 11.5	10	53	51	.190
11.5 - 14.5	13	34	35	.029
14.5 - 17.5	16	27	23	.696
17.5 - 20.5	19	21	15	2.400
20.5 - 23.5	22	13	10	.900
23.5 - 26.5	25	13	6	8.167
26.5 - 29.5	28	9	4	6.250
29.5 - 32.5	31	8	2	18.000
		$\Sigma f_s = \underline{490}$		$V_1 = \underline{40.191}$

$\bar{X} = 7.943$

The distribution of the test statistic V_1 will be approximately a chi-square distribution if the interarrival distribution is exponential. The test statistic is given by:

$$V_1 = \Sigma(f_s - f_e)^2/f_e$$ where f_s is an observed sample frequency and f_e is the corresponding expected frequency.

The value on the chi-square scale for 7 degrees of freedom* and .05 level of significance (α = .05) is 14.067. Since $V_1 > 14.067$, the expectation that the distribution is exponential was rejected.

A smooth curve was drawn from the histogram in Figure 9 and it is assumed that this will represent the empirical distribution when the sample becomes increasingly large. The probabilities and culmulative probabilities of the interarrival times derived from the smoothed curve are shown in Table II. These probabilities were used in the simulation.

<u>Hourly Fluctuations of Arrival.</u>

In a study undertaken by the Nuffield Provincial Hospitals Trust (Towards a Clearer View ..., 1962. p. 55), it was found that the workload of the six radiology departments investigated was dominated by two major peak periods. This is an important consideration since

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* There are 9 classes of f_e where the sample size is 5 or greater. Therefore, there are 9 - 2 = 7 degrees of freedom.

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

TABLE II

PROBABILITIES OF INTERARRIVAL TIME
OBTAINED FROM THE CONTINUOUS ARRIVAL DISTRIBUTION

Inter-arrival time	Frequency	Probabilities of Arrival	Culmulative Probabilities
0	60	.1278	.1278
1	50	.1031	.2309
2	42	.0866	.3175
3	36	.0742	.3917
4	32	.0660	.4577
5	28	.0577	.5154
6	25	.0516	.5670
7	23	.0474	.6144
8	21	.0433	.6577
9	18	.0371	.6948
10	16	.0330	.7278
11	15	.0309	.7587
12	13	.0268	.7855
13	12	.0247	.8102
14	12	.0247	.8349
15	9	.0186	.8535
16	9	.0186	.8721
17	8	.0165	.8886
18	7	.0144	.9030
19	6	.0124	.9154
20	6	.0124	.9278
21	5	.0103	.9381
22	4	.0083	.9464
23	4	.0083	.9547
24	4	.0083	.9630
25	3	.0062	.9692
26	3	.0062	.9754
27	2	.0041	.9795
28	2	.0041	.9836
29	2	.0041	.9877
30	2	.0041	.9918
31	2	.0041	.9959
32	2	.0041	1.0000

$\bar{X}$ = Mean = 7.462

peak periods affect the use of x-ray rooms, the activities of the technicians and radiologists, and the waiting time of patients.

In order to find out whether such fluctuations of arrival exist in the hospital under consideration, the number of arrivals for each thirty minutes of the day was summarized and a histogram was plotted. The result of the ten-day period is shown in Figure 10. The figure shows two types of arrival: controllable (i.e. inpatient) and uncontrollable (i.e. outpatient). Two peaks are seen for the arrival pattern of uncontrollable patients. However, in this hospital, attempts were made by the control clerk to spread the workload.* This is evidenced by the many arrivals of controllable patients during the off-peak periods. The spreading of workload in this hospital results in not-too-vigorous fluctuations of "peaks" and "valleys".

The model to be developed will not consider "peaks" for the above reason.

Daily Fluctuations of Arrival.

It was suspected that an uneven amount of workload occurred daily as well as monthly. Such fluctuations should be considered in deciding facility requirements.

To test the existence of fluctuations in workload during weekdays, four weeks' sample of arrivals were taken and a one-way

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* see "Description of the Radiology Department," p. 11.

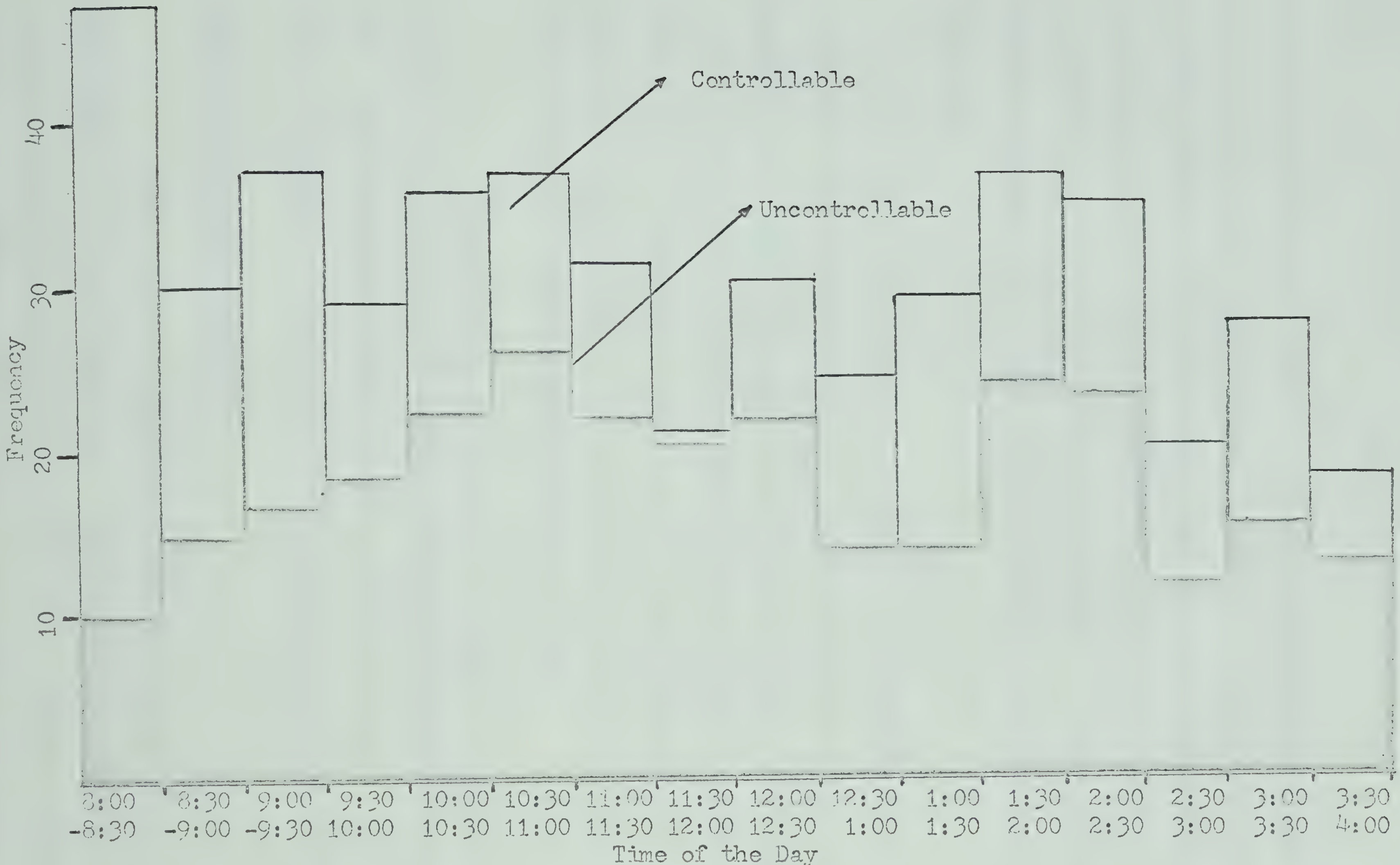

FIGURE 10. HOURLY FLUCTUATIONS OF ARRIVAL

analysis of variance was tested to compare different population means. Table III shows the 20 days' sample. Statistical theory shows that the total variation, Q, can be broken into (i) the inherent variations in the sample observations for each of the treatment (weekdays) - i.e., the variation within the columns in Table III and (ii) the variations between treatments - i.e., the variations between the columns in the same table.

To decide whether to conclude the presence of any fluctuations during the weekdays, we compare the ratio of the within-treatments mean square (MS_2) with the between-treatments mean square (MS_1). See Table IV. If the treatment means are dqual, the test statistic V_1 is distributed according to an F-distribution. For this example, the F-scale value for $\alpha = .05$ is 3.06. Since $V_1 > 3.06$, we conclude that the treatment means are not all equal.

From the data in Table III, it seems that there are more arrivals at the beginning of the week and fewer towards the end of the week. The interarrival time distribution shown in Figure 9 is, in effect, an average of the fluctuations that occur during the weekdays.

Monthly Fluctuations of Arrival.

The monthly variations of workload can be tested in the same manner as the daily variations. The data for two years were used in the sample and the calculation for the test is shown in Table V. The result shows that the mean arrival of each month is the same at $\alpha = .05$.

TABLE III

PATIENT-LOAD DURING WEEK-DAYS
FOR FOUR WEEKS

Sample Observation	Days: M	Tu	W	Th	F
W1	63	55	40	44	45
W2	65	58	47	46	37
W3	64	59	60	47	40
W4	60	60	55	48	43
Total:	252	232	202	185	165
Mean:	63.00	58.00	50.50	46.25	41.25

Overall Mean $\bar{\bar{X}}$: $\frac{63.00 + 58.00 + 50.50 + 46.25 + 41.25}{5}$

$= 51.80$

TABLE IV

TEST CONCERNING FLUCTUATIONS OF
ARRIVAL DURING WEEK-DAYS

Within Treatments Sum of Squares, $Q_1 = \sum_j \sum_i (X_{ij} - \overline{X}_j)^2$

where i = row or sample observation (1, 2, 3, 4)
j = column or treatment (1, 2, 3, 4, 5)

$Q_1 = 14 + 14 + 233 + 8.75 + 36.75 = 306.50$

Between Treatments Sum of Squares, $Q_2 = \sum_j n(\overline{X}_j - \overline{\overline{X}})^2$

$Q_2 = 501.76 + 153.76 + 6.76 + 123.21 + 445.21 = 1230.70$

	Q_2	Q_1
sum of squares	1230.70	306.50
degrees of freedom	$\delta_2 = 4$	$\delta_1 = 15$
mean square	307.675	20.433
test statistic V_1	$MS_2/MS_1 = 15.058$	

TABLE V

TEST CONCERNING FLUCTUATIONS OF MONTHLY ARRIVAL

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	Months of the Year											
1967	925	903	948	848	965	923	880	913	891	984	968	886
1968	1027	980	1021	1030	1049	928	1014	876	936	1045	1016	914

$$Q_1 = \sum_i \sum_j (X_{ij} - \overline{X}_j)^2 = 45{,}008.500$$

$$Q_2 = \sum_j n(\overline{X}_j - \overline{\overline{X}})^2 = 36{,}347.108$$

	Q_2	Q_1
Sum of squares	36,347.108	45,008.500
Degrees of freedom	$\delta_2 = 11$	$\delta_1 = 12$
Mean square	3304.282	4000.700

Test statistic, $V_1 = MS_2/MS_1 = 0.8259$

F-distribution at $\alpha = 0.05$ is 2.27

A look at the sample data shows that there is a slight seasonal variation, though this is not very significant. Fewer arrivals occurred in December, but the periods both following and preceding it were somewhat higher. There are reasons to suspect that patients would either have their examinations before Christmas or delayed them until the season is over. The summer months also show fewer arrivals. The sample for 1968 shows that there was a distinct increase of patients over the previous year.

Number of Emergencies.

From the two-week sample, there were 127 cases of emergency and 373 cases of non-emergency. Table VI shows that the number of emergencies experienced each day were about the same.

Service Pattern

Identification of Examination-Types.

There are 210 separate bones in the skeleton (Jacobi and Paris, 1964. p. 119). It is therefore not surprising that there are many types of examination performed at a radiology department. Hodges, *et al*. (1964. p. 46) identify nine types of examination (or examination-types) performed at the radiology department. For this study, seven categories of examination-types are identified as belonging to general radiographic examination. Figure 11 below shows the seven categories. The classification is based upon similarities of procedures and examination time.

[illegible] following [illegible]

TABLE VI

FREQUENCIES OF EMERGENCY

DAY	NUMBER OF EMERGENCIES
M	17
Tu	12
W	14
Th	14
F	12
M	14
Tu	15
W	8
Th	10
F	11
	127

Proportion of Emergencies = p = 0.254

Estimated variance of p = σ_p^2 = 0.0004

EXAMINATION-TYPE	DESCRIPTION
1	Upper extremities - includes thumb, fingers, hand, wrist, forearm, elbow, humerus, radius & ulna. Excludes shoulder.
2	Lower extremities - includes foot, ankle, knee, toe, femur, heel, thigh, tibia & fibula.
3	Vertebral column - except complete spine, hip, pelvis.
4	Skull & brain
5	Head & neck - includes sinuses, mastoids, facial bones.
6	Complete spine, pelvimetry, hip, pelvis, shoulder.
7	Abdomen

FIGURE 11. EXAMINATION-TYPES

Daily Variation of Examination-Types.

If a probability could be calculated corresponding to each examination-type, then the simulation would present little difficulty. However, it was suspected that the probability of each examination-type may vary from day to day. To find out whether such variations exist, a test of independence was performed for both weeks of our sample. Table VII shows the data for the second week. The sample shows 247 arrivals in which 201 have one type of examination, 31 have two types of examination, and 15 have three types of examination.

TABLE VII

SAMPLE OF 308 EXAMINATIONS CROSS-CLASSIFIED
BY WEEKDAYS AND EXAMINATION-TYPES

	Days of the Week					
Exam.-Types	D1	D2	D3	D4	D5	Total
T1	14	13	10	13	15	65
T2	30	13	7	20	12	82
T3	5	8	2	5	6	26
T4	8	7	15	5	4	39
T5	2	4	6	6	5	23
T6	19	14	10	5	8	56
T7	4	6	1	2	4	17
	82	65	51	56	54	308

Test statistic, $V_1 = \Sigma(f_s - f_e)^2/f_e = 44.081$

The chi-square scale corresponding to $\alpha = .05$ and $\delta = (7 - 1)(5 - 1) = 24$ is 36.415. Since $V_1 > 36.415$, we conclude that the "examination-types" and "days" are statistically dependent.

The sample for the first weeks was also analyzed and the conclusion was the same. The analysis shows that it is difficult to attach a probability to each examination-type owing to the changing nature of examination requirements.

Variation of Examination-Types for Corresponding Weekdays.

As an alternative we may consider that if all Mondays, (all Tuesdays, and so on) were statistically independent, we could still attach a probability for each examination-type. This means that the probability of each examination-type changes from Monday to Friday, but the probability for all Mondays, for instance, will remain unchanged.

The two Mondays in the sample were tested and the result shows that they were statistically independent at $\alpha = .05$. However, when the two Wednesdays were tested, the result shows dependency. Consequently, this method cannot be employed.

Distribution of Service Time.

Owing to the changing nature of examination requirements, which results in difficulties of calculating probabilities for each examination-type, it was decided that the examination time for the 500 patients be plotted on a graph. The graph is shown in Figure 12. The observed curve seems to fit a poisson distribution.

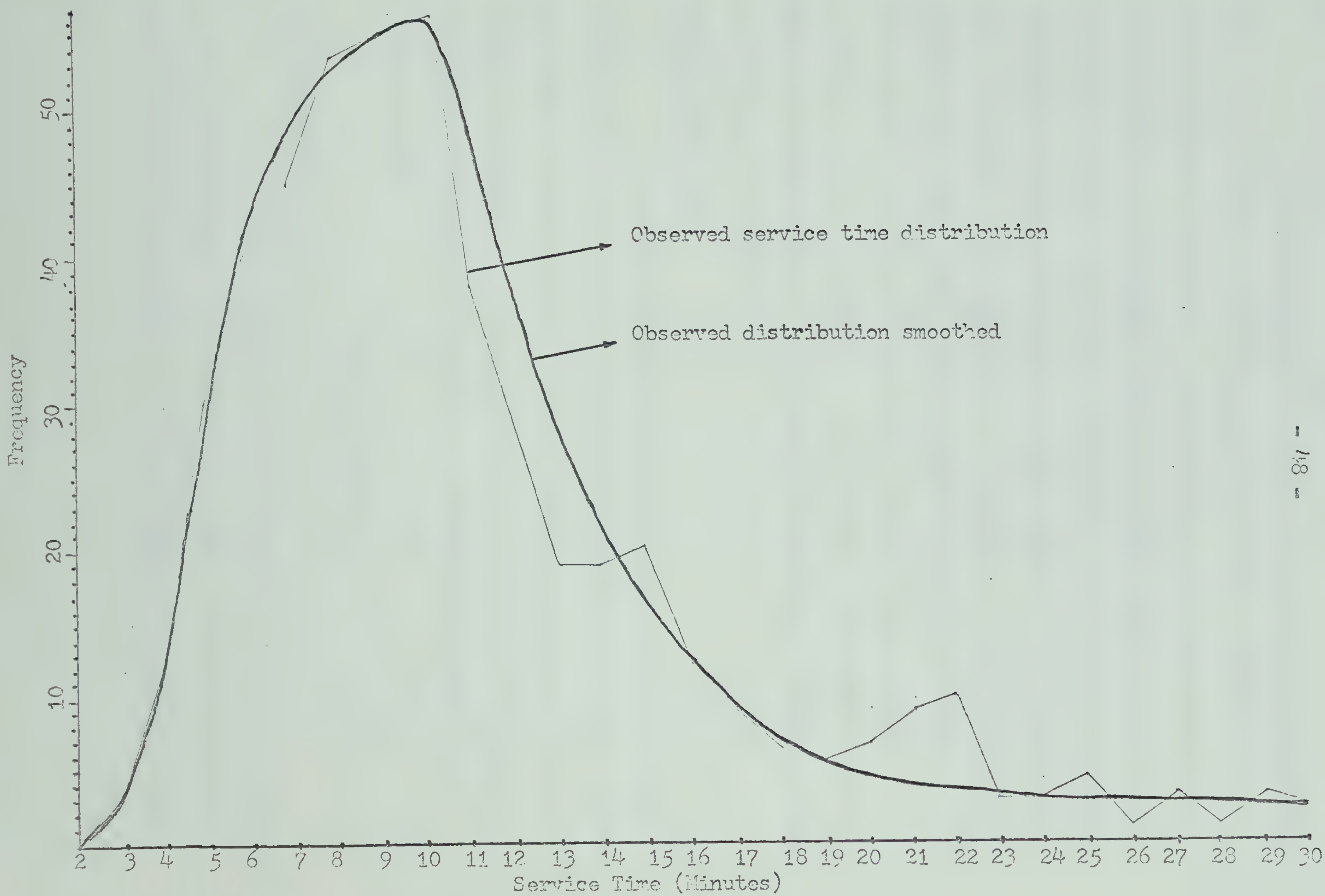

FIGURE 12. SERVICE TIME DISTRIBUTION

The goodness-of-fit test for the poisson distribution was performed in the same manner as the exponential distribution. Table VIII shows the result. The chi-square scale corresponding to $\alpha = .05$ and $\delta = 13$ is 22.362. Since $V_1 > 22.362$, the hypothesis that the observed curve fits a poisson distribution was rejected. A smooth curve was drawn from the observed distribution and it is assumed that this will represent the empirical distribution when the sample become increasingly large. Curve fitting techniques could be employed to obtain a more accurate fit than shown. However, the increased accuracy would not be justified in this study. The probabilities and culmulative probabilities of the service time derived from the smoothed curve is shown in Table IX.

Number of Re-x-rays.

From the two-week sample, 154 patients were re-x-rayed because the quality of the films were not satisfactory. Table X shows the number of unsatisfactory film experienced for each day. For the purpose of determining the probability that a patient will require a re-x-ray, we shall take the average of the two-week sample. The figure is 0.308.

Waiting Pattern

For Processing of Film.

When the film is taken to the Dark Room, it is processed and the content comes out of the O-xmat machine. The time taken for this process is approximately 8 minutes. Normally, queuing of films

TABLE VIII

CALCULATION OF TEST STATISTIC FOR
DECISION CONCERNING SERVICE TIME

Service time X	Sample Frequency f_s	Estimated Expected Frequency f_e	Relative Squared Deviation
0 - 4	15	8.0780	5.9314
5	30	11.8335	27.8888
6	40	21.4975	15.9248
7	45	33.4745	3.9683
8	53	45.6090	1.1977
9	55	55.2375	.0010
10	56	60.2090	.2942
11	38	59.6615	7.8647
12	32	54.1925	9.0881
13	19	45.4385	15.3833
14	19	35.3775	7.5817
15	20	25.7080	1.2674
16	12	17.5135	1.7357
17	9	11.2290	.4425
18 - 30	57	14.9405	118.4031
	f_s = 500	500.0000	V_1 = 216.9727

$\overline{X}$ = 10.948

TABLE IX

PROBABILITIES OF SERVICE TIME
OBTAINED FROM THE SMOOTHED SERVICE DISTRIBUTION

Service Time	Frequency f	Probabilities of f	Cumulative Probabilities
3	3	.0016	.0016
4	12	.0087	.0103
5	30	.0271	.0374
6	43	.0467	.0841
7	49	.0621	.1462
8	53	.0767	.2229
9	55	.0896	.3125
10	56	.1014	.4139
11	49	.0976	.5115
12	38	.0825	.5940
13	28	.0659	.6599
14	21	.0532	.7131
15	16	.0434	.7565
16	12	.0348	.7913
17	9	.0277	.8190
18	7	.0228	.8418
19	5	.0172	.8590
20	4	.0145	.8735
21	4	.0152	.8887
22	3	.0119	.9006
23	3	.0125	.9131
24	3	.0130	.9261
25	3	.0136	.9397
26	3	.0141	.9538
27	3	.0147	.9685
28	2	.0101	.9786
29	2	.0105	.9891
30	2	.0109	1.0000
		1.0000	

Mean $\overline{X} = 10.667$

TABLE X

FREQUENCY OF RE-X-RAYS

DAY	TOTAL ARRIVALS	NO. OF RE-X-RAYS
M	65	29
Tu	58	25
W	47	11
Th	46	13
F	37	7
M	63	22
Tu	55	9
W	40	13
Th	44	16
F	45	9
	500	Total: 154

Probability of re-x-ray = p = 0.308

Estimated variance of p = σ_p^2 = 0.0004

does not occur in the Dark Room. When the films come out of the O-xmat machine, they are checked by quality technicians. In almost all cases, the quality of the films are determined at this point. However, if a decision cannot be made, the film goes to a radiologist for the final decision. Obviously, if this happens, further delay occurs.

In this study, we shall assume that the processing time of the film is 8 minutes.

For Porter.

It was mentioned earlier that the waiting time for a porter has no affect on the waiting time before examination. However, it is included here to complete the operation of the department.

A two-day survey on April 22 and April 29 shows that 35 patients require portering service out of 113 arrivals. The estimated probability that an arrival will require a porter is then 0.309. The waiting time for a porter for the 35 patients is shown in Figure 13.

It should be pointed out that a larger sample size should be taken before we can make any definite conclusions on the distribution of waiting time for porter. A more complete study should include the service of porters to "special" patients, absenteeism of porters, daily fluctuations of patient requiring porters, and the like. These have not been considered in this study.

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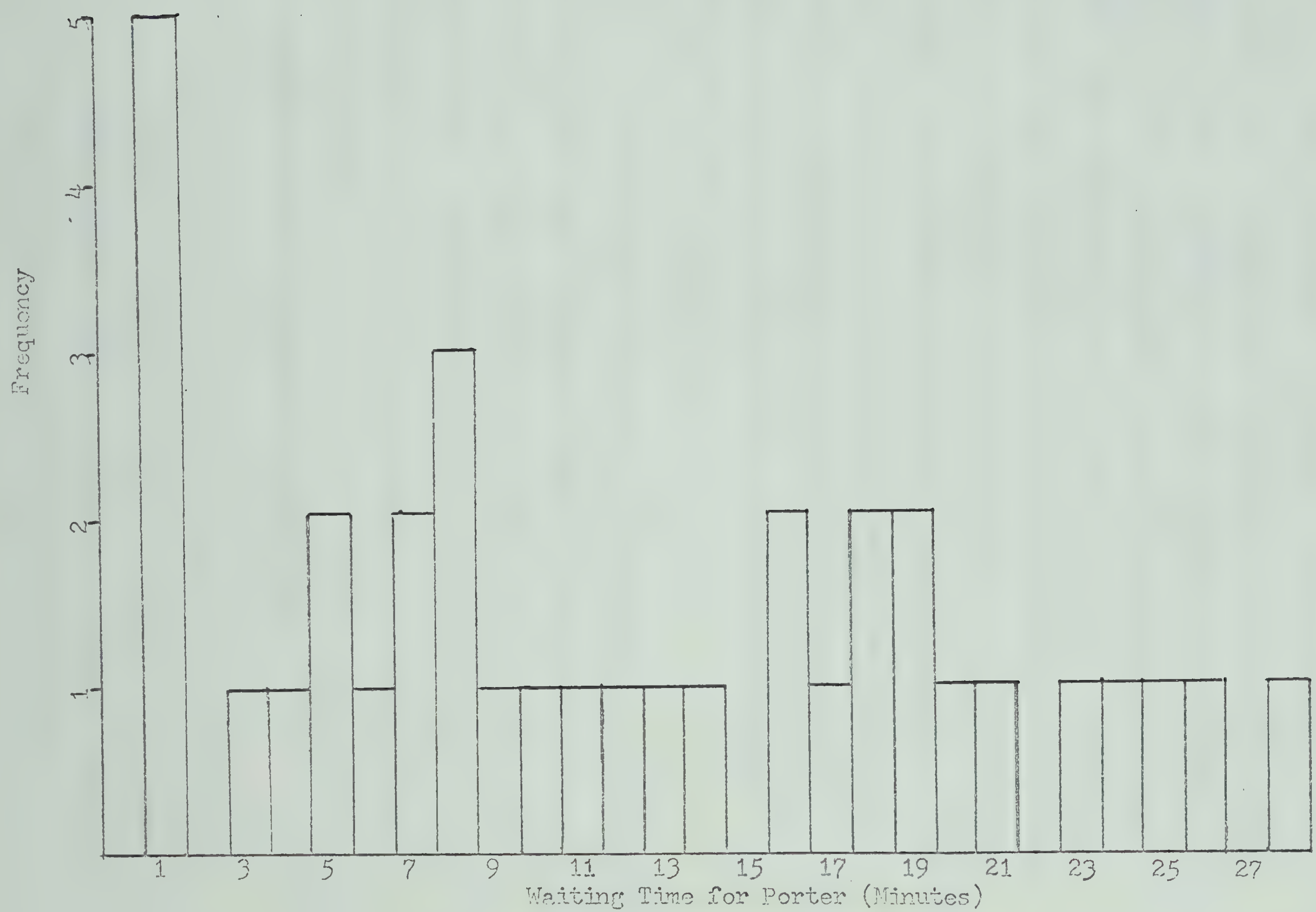

FIGURE 13. PORTER TIME DISTRIBUTION

Manual Simulation of the System

The flow diagram of Figure 7 is not an exact representation of the system, but the important characteristics were considered. Before a computer model of the system was programmed, a manual simulation was undertaken by using the parameters already estimated. The tabular form not only allows us to state the flow diagram more completely and accurately, but it also permits us to make an initial value judgement concerning its adequacy in comparison to the real system. Table XI shows the results of a manual simulation of 18 arrivals. The column headings contain the symbols (see Figure 6) of the various phases each patient goes through. The simulation is successful in portraying the flow of the patients considering the assumptions mentioned in chapter II.

From the manual simulation, a few assumptions were noted (listed below) which were not evident before. At the same time, we noticed a few significant factors (listed below) which have not been considered so far. Since the value of a simulated model depends on how closely it predicts the real world situation, these factors require further considerations.

Further assumptions made in the model to be developed.

I. The model does not consider patients who may not have to wait for their films to be processed. This happens when a patient, after a general radiographic examination, goes directly to another x-ray room for special

TABLE XI

MANUAL SIMULATION OF THE SYSTEM

PN	RN	AT(PN)	CLOCK	RN	EMG(PN)?	QT(PN)	RN	TOTIME(PN)	BEGIN(PN) RM1	BEGIN(PN) RM7	END(PN) RM1	END(PN) RM7
1	0399	0	8:00	908	no	0	1547	8	8:00		8.08	
2	3855	3	8:03	780	no	0	2009	8		8:03		8:11
3	1754	0	8:03	559	no	5	7678	16	8:08		8:24	
4	3264	3	8:06	875	no	5	6053	13		8:11		8:24
(1)	-	-	8:16	-	-	6	5105	11		8:24		8:35
5	6957	10	8:16	168	yes	8	4137	10	8:24		8:34	
6	2412	2	8:18	346	no	25	1861	8		8:43		8:51
7	6119	7	8:25	453	no	34	5831	12	8:59		9:11	
8	3053	2	8:27	597	no	33	6219	13		9:00		9:13
9	4378	4	8:31	165	yes	3	9318	25	8:34		8:59	
(3)	-	-	8:32	-	-	3	1862	8		8:35		8:43
(3)	-	-	8:51	-	-	0	3062	9		8:51		9:00
10	9948	32	9:03	335	no	8	6596	13	9:11		9:24	
11	5570	6	9:09	595	no	4	2028	8		9:13		9:21
(7)	-	-	9:19	-	-	2	6213	13		9:21		9:34
12	8086	13	9:22	205	yes	2	5936	12	9:24		9:36	
13	3356	3	9:25	594	no	9	4978	11		9:34		9:45
14	9089	19	9.44	426	no	0	9371	25	9:44		10:09	
15	7803	12	9:56	349	no	0	3288	10		9:56		10:06
16	5598	6	10:02	993	no	4	9205	24		10:06		10:30
17	8753	17	10:19	664	no	0	9581	27	10:19		10:46	
18	1681	1	10:20	485	no	10	3951	10		10:30		10:40

TABLE XI (CONTINUED)

PT(PN)	RN	QGD(PN)?	ENDPT(PN)* (CLOCK)	RN	POT(PN)?	RN	TPOT(PN)	DISMISSAL TIME FOR POT(PN) (CLOCK)
8	276	no	8:16	-	-			
8	929	yes	8:19	011	yes	0984	1	8:20
8	102	no	8:32	-	-			
8	758	yes	8:32	962	no			
8	496	yes	8:43	558	no			
8	857	yes	8:42	439	no			
8	412	yes	8:59	019	yes	8563	21	9:20
8	058	no	9:19	-	-			
8	824	yes	9:21	668	no			
8	749	yes	9:07	111	yes	9873	28	9:35
8	202	no	8:51	-	-			
8	484	yes	9:08	774	no			
8	608	yes	9:32	856	no			
8	435	yes	9:29	748	no			
8	887	yes	9:42	285	yes	0711	1	9:43
8	948	yes	9:44	781	no			
8	744	yes	9:53	740	no			
8	749	yes	10:17	654	no			
8	613	yes	10:14	660	no			
8	765	yes	10:38	083	yes	0375	1	10:39
8	116	no	10:54	-	-			
8	928	yes	10:48	009	yes	2703	6	10:54

* Dismissal time for PNth patient with QGD (quality of film satisfactory) and NPT (no porter needed).

examination. Conversely, a patient who has completed a special examination may be directed for a general radiographic examination. This does not occur frequently.

II. The model does not assign a patient to the x-ray room on a random basis. But it will assign a patient to Room 1 (if it is empty) before Room 7. Therefore, Room 1 will be utilized more than Room 7.

III. A patient who requires a re-x-ray may take a disproportionate amount of time in comparison to the first x-ray. That is, he may take three minutes for the first examination but twenty minutes for the re-x-ray.

IV. The model does not show where a patient comes from (i.e. ward, Student Health Services, etc.). All arrivals, with the exception of emergencies, are considered identical in that they are all patients and will be served on a first-come-first-served basis.

V. Cases of emergency may end up waiting for a porter. In reality, they do not need a porter from this department because a porter from the Emergency Department normally accompanies the patient.

VI. All re-x-rays are assigned second highest priority (see Figure 7). In effect, if the patient requiring a re-x-ray is classified as emergency (EM), the second highest priority would still be assigned to him. In reality, emergencies should always have the highest

priority. Also, there should be priority levels within emergencies. It is assumed that this simplification does not lead to any significant error.

VII. In the real system, an emergency patient may be taken away after his x-ray instead of waiting for the film to process. This has not been considered.

Further considerations needed for completeness.

I. The manual simulation shows that at 8:00 a.m. the Waiting Room is empty. This is usually not true at the department. At the time the sample was collected it was observed that there were, on an average, 2 patients. This may differ in the winter months, but we shall assume the starting condition to consist of 2 patients.

II. Lunch time and coffee breaks have not been considered. The breaks are taken on a shift basis with 3/4 hour for lunch and 1/4 hour for coffee. For the purpose of constructing the computer model, we shall assume that Room 1 is closed from 11:00 p.m. to 12:00 p.m. and Room 7 is closed from 12:00 p.m. to 1:00 p.m. This will not be necessary for Room 2 since it starts at 1:00 p.m.

III. The manual simulation shows that as long as there are patients waiting, the technicians will be fully occupied in taking x-rays. A one-day check reveals that a portion of the technicians' time is involved in other activities. The activities of the technicians are summarized below.

A. <u>Activities of technicians when there are patients waiting</u>.

(i) Performing examination.

1. receiving patient, positioning patient and equipment.
2. fixing unexposed film encased in cassettes, adjusting machine, if necessary.
3. taking x-rays (and re-positioning patient and/or machine as required).
4. removing patient.

(ii) Unavoidable time lapse that occurs between examinations.

1. cleaning up room when necessitated by the examination just completed.
2. picking up requisition at the Control Board and calling for patient; if necessary.
3. pushing patient into the x-ray room and pushing him out after examination, if necessary.
4. studying requisition.
5. waiting for patient to walk into room.
6. completing paperwork after examination.
7. taking film to Dark Room.
8. going to rest-room, answering telephone calls, etc.

(iii) Talking to colleagues, physicians, radiologists, patients, or students.

B. <u>Activities of technicians when there is no patient</u>.

(i) Housekeeping - including restocking film cabinets, cleaning equipment and room, etc.

(ii) Explaining work to student trainee.

(iii) Talking to colleagues, physicians, radiologists, or patients.

(iv) Waiting for patient.

It is noticed that the "examination time" should really include A(ii) and A(iii) if we consider these activities as unavoidable. The one-day survey during the busy hours shows that 90% of the time is spent in A(i) and the rest is spent on A(ii) and A(iii).

It should also be noted that the "idle time" of the technicians should not be considered as totally unproductive. Part of the time which is considered "idle" is engaged in B(i) and B(ii), which is partially productive, if not totally productive.

GATHERING STATISTICS

The simulator automatically maintains certain statistics as transactions pass through the system. Such "standard output" may include statistics pertaining to FACILITIES, STORAGES, QUEUES, etc. Certain outputs can be requested through a TABULATE block and a TABLE card. A TABLE consists basically of frequency classes which permits the statistics to be gathered in a fashion that provides meaningful information to the user.

The GPSS/360 Output Editor permits the user to modify the standard output into a format more appropriate to a given application. Various options are available. This includes the use of TITLE card, INCLUDE card, FORMAT card, TEXT card, etc.

ORGANIZING THE COMPUTER MODEL

There are 43 distinct blocks in the GPSS/360 program (GPSS/360, 1967. pp. 44-52) and these are standardized packages, each containing several statements in a more general computer language. The system being simulated is described in the form of a block diagram. Each block represents a specific action representing some basic operation of the real system. From the flow diagram in Figure 7, a block diagram can be developed. The block diagram of Figure 14 represents two x-ray rooms. The block diagram shows the various steps of the system and the sequence in which patients proceed from one step to another. The blocks are shown in conventional symbols, and a block

CHAPTER V

FORMULATION OF A COMPUTER MODEL

TIME-FLOW MECHANISM

In the GPSS/360 program,* transactions move from block to block in a manner very similar to the real system. The program computes an action time for each transaction that enters the block. The time is maintained by a clock that records the instant of real time reached in the system. This is called the "clock time". The clock time is represented by an integral number. The unit of clock time can assume any unit such as millisecond, hour, year, etc. corresponding to the real system.

The number of transactions to be created by the simulation model can be controlled by Field D of the GENERATE block. However, at the radiology department, it would be more realistic to control the time from 8:00 a.m. to 4:00 p.m. rather than controlling the exact number of transactions. One way to terminate the simulation at 4:00 p.m. is to use a TEST block. An alternative is to employ an ADVANCE block. The latter is adopted in this study and the details will be explained below.

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* No attempt is made to describe the GPSS language in detail.

[illegible]

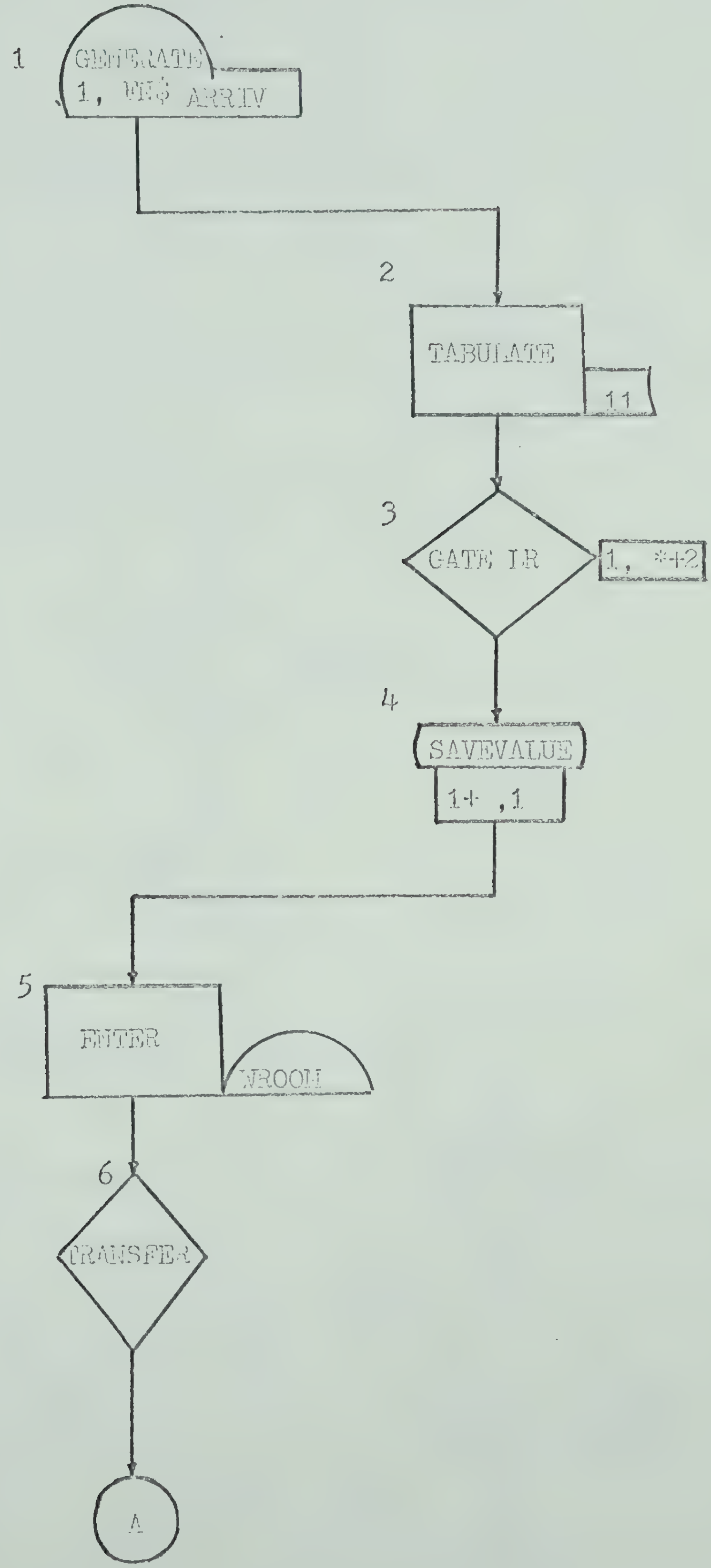
[illegible]

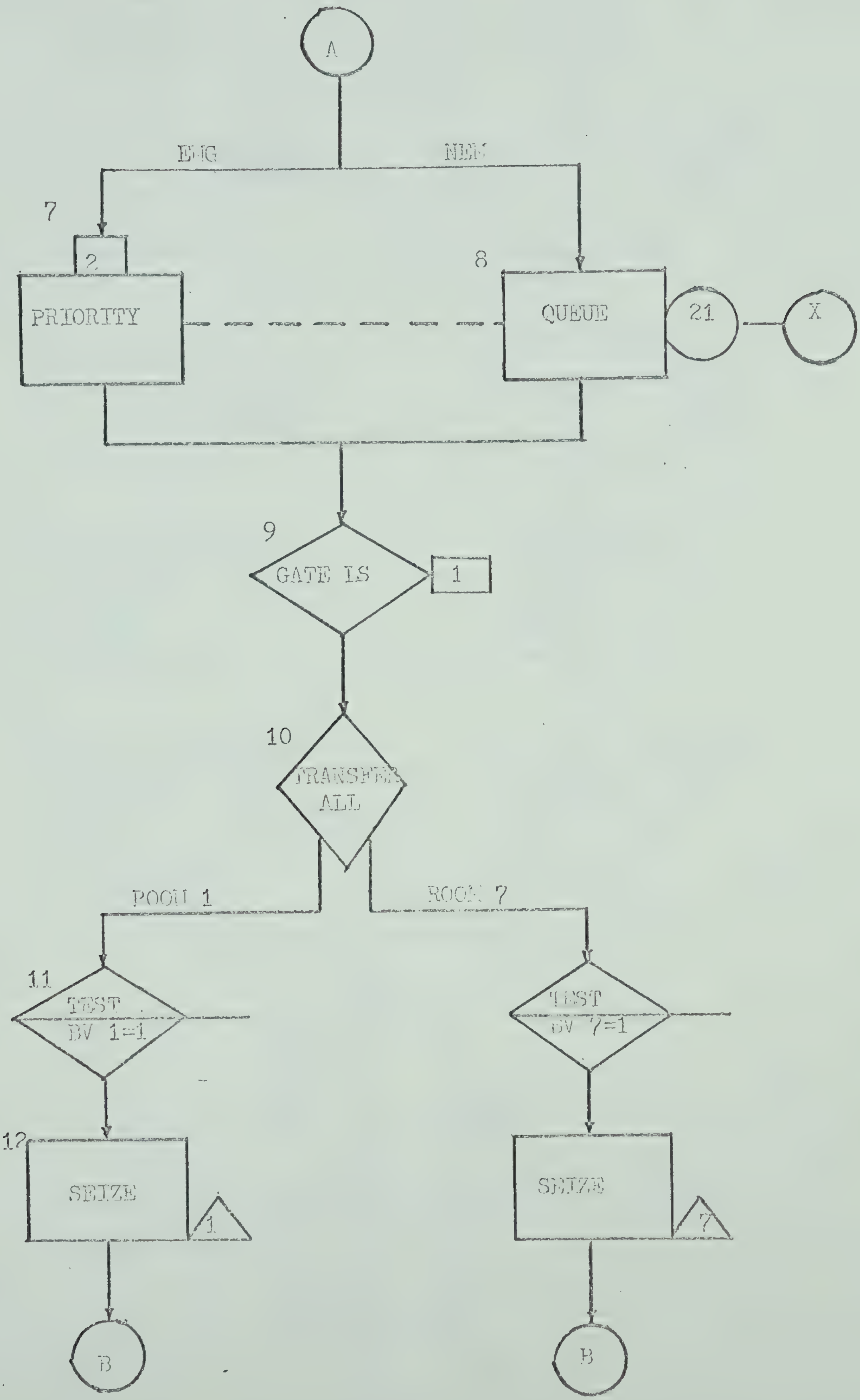
[illegible]

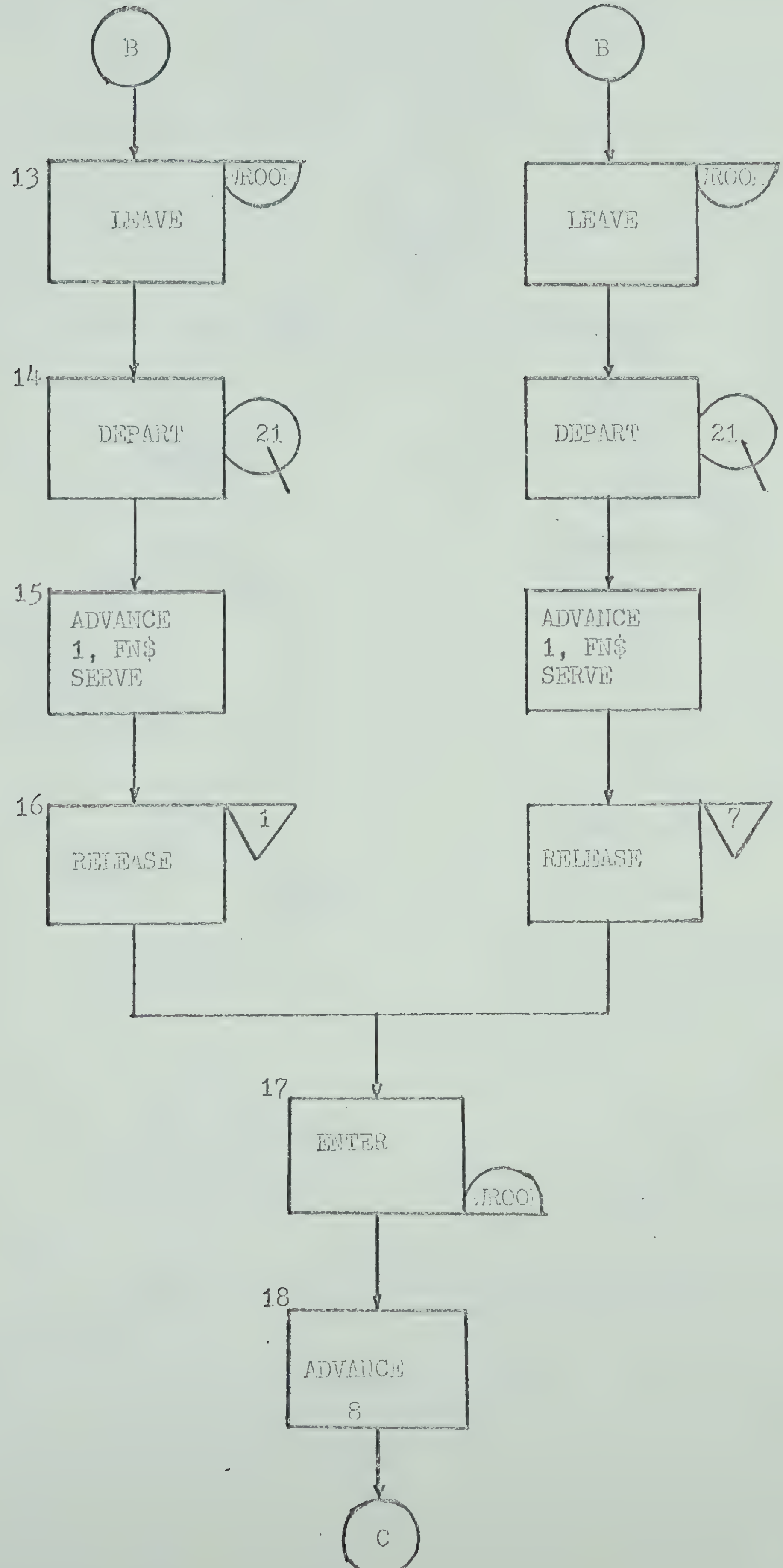
[illegible]

[illegible]

[illegible]


1
GENERATE
1, FN$ ARRIV
2
TABULATE
11
3
GATE IR
1, *+2
4
SAVEVALUE
1+ ,1
5
ENTER
WROOM
6
TRANSFER
A


A
EMG
NEM
7
2
PRIORITY
8
QUEUE
21
X
9
GATE LS
1
10
TRANSFER
ALL
ROOM 1
ROOM 7
11
TEST
BV 1=1
TEST
BV 7=1
12
SEIZE
1
SEIZE
7
B
B


B
B
13
LEAVE
LEAVE
14
DEPART
21
DEPART
21
15
ADVANCE
1, FN$
SERVE
ADVANCE
1, FN$
SERVE
16
RELEASE
1
RELEASE
7
17
ENTER
18
ADVANCE
8
C

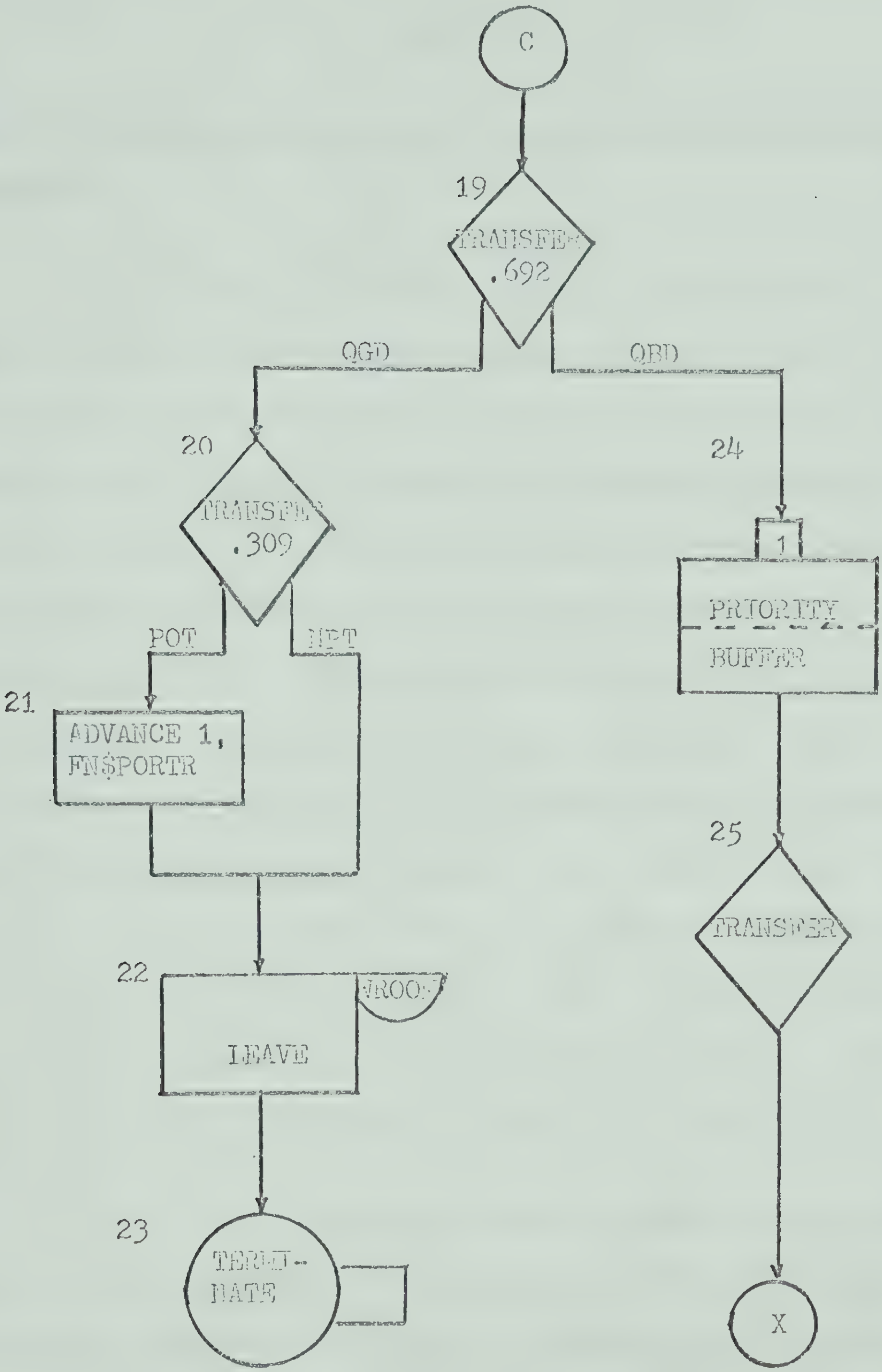


FIGURE 14. BLOCK DIAGRAM OF THE SYSTEM

number is indicated in each case. Each block may be considered as one statement.

Block 1 simulates arrivals of patient into the system at clock times prescribed by the interarrival distribution of Table II. The function ARRIV must be defined earlier in the program. This function has a mean of 1. Blocks 2 to 4 are not transaction entities. Block 2 TABULATEs all arrivals in a TABLE identified as Number 11. The TABLE and the manner in which arrivals are to be tabulated, are previously defined. The GATE block (Block 3) is used to test the status of an arrival. The unconditional entry mode of the GATE block permits all transactions to enter. If a patient arrives at the department before 8:00 a.m., he will be added to the current value of SAVEVALUE 1 (Block 4) which is initially zero. The Standard Logical Attribute LR1 of Block 3 must be "true" (GPSS/360, 1967. p. 131) before 8:00 a.m. so that transactions can move to the SAVEVALUE block. After 8:00 a.m., transactions will be directed to Block 5 via field B of the GATE block.

Block 5 permits patients to ENTER the Waiting Room. If the referenced STORAGE, with the initial WROOM, has reached 20 patients, a transaction will not be permitted to enter because there is not enough available space to accommodate further transactions. The chance of a "no-entry" is unlikely to occur because the Waiting Room in the real system is shared between scheduled and non-scheduled patients. Non-scheduled patients only occupy part of the Waiting Room. Block 6 decides whether an arrival is an emergency (EMG) or a non-emergency (NEM). The probability that an arrival is an EMG is .254.

If the patient is an EMG, PRIORITY 2 (Block 7) is assigned to him. Otherwise, he waits at the QUEUE identified as Number 21 (Block 8). The dotted lines show that an EMG patient may or may not have to wait at the QUEUE.

Block 9 holds up all transactions until the GATE "opens" at 8:00 a.m. This is controlled by a LOGIC SWITCH 1 which is "set" at 8:00 a.m.* Block 10 TRANSFERs an arrival to Room 1. If Room 1 is occupied, Room 7 will be tested. It is possible to use the ALL or BOTH selection mode of the TRANSFER block to permit an entering transaction to exit via the field B next block. If conditions are not met for entry into this block, the transactions will try the field C next block.

Since the operation of all x-ray rooms for general radiographic examination is identical, only Room 1 will be explained below. Block 11 permits entries to be TESTed with a Boolean Variable identified as number 1. If entries are permitted, the Boolean variable should produce a result of one. (GPSS/360, 1967. p. 23). This is only true if the facility is not occupied and the technician is not having his lunch break.** If this condition is met, Block 12 allows the transaction to occupy Room 1 by SEIZing the transaction. Blocks 13

---

* See Block 28 of Figure 15. Page 72.

** 1 BVARIABLE LR2*FNU1.
Explanation: Boolean variable of Room 1 will produce a result of one only when LOGIC SWITCH 2 is in a reset condition and Room 1 is not in use.

and 14 enable the patient to LEAVE the Waiting Room and DEPART from Queue 21.

The time spent in the x-ray room (Block 15) is prescribed by a service time distribution identified as SERVE. The function SERVE has been previously defined with a mean of 1. It is obtained from Table IX where the service time has been multiplied by 100/90.* Blocks 16 RELEASEs the transaction from Room 1 after the examination.

After the examination, the transaction ENTERs the Waiting Room (Block 17) and waits for 8 minutes (Block 18) while his film is being processed. At the end of 8 minutes, a decision is made with regards to the quality of his film. Block 19 TRANSFERs 69.2 percent of all transactions to QGD (quality satisfactory). If the patient's film is classified as QGD, the next move is to decide whether he needs portering service (Block 20). The chance is .309 that he needs a porter. If he needs a porter, he may have to wait (Block 21); otherwise, he LEAVEs the Waiting Room (Block 22) and the transaction is removed from the system (Block 23).

A patient whose film turns out to be QBD (quality unsatisfactory) has to be re-x-rayed and he joins Queue 21 again. Block 25 TRANSFERs the patient to Block 8 to represent this transaction. A patient who requires a re-x-ray is also given priority over other patients except cases of emergency. Therefore, priority 1** is specified

---

* See page 60.

** Priority 2 is ahead of all transactions that have a priority of 1 or less.

in field A of the PRIORITY block (Block 24). At the same time, a BUFFER option is assigned to this PRIORITY block. This permits the GPSS/360 scan to move all emergencies in the current events chain ahead of the re-x-rays (GPSS/360, 1967. p. 96).

The third room (Room 2) is in operation only in the afternoon from 1:00 p.m. to 4:00 p.m. It was not described above but it is similar to the other two rooms.

It was mentioned above that the number of transactions could be controlled by the clock. This is shown in Figure 15. The time is GENERATEd (Block 26) for 10 minutes (Block 27) before the GATE (Block 9 of Figure 14) is "opened" by LOGIC SWITCH 1 (Block 28). The 10 minutes of Block 27 create about 2 patients arriving before 8:00 a.m.

Patients are served at Room 1 and 7 from 8:00 a.m. to 4:00 p.m. with the exception of lunch breaks. The clock control for each room is similar; consequently, only Room 1 will be explained in some details.

Block 29 ADVANCEs the clock for 180 minutes (i.e., from 8:00 a.m. to 11:00 a.m.). During this period, entries are permitted into Rooms 1 and 7 as the LOGIC SWITCHES for both rooms are initially in a "reset" condition.* At 11:00 a.m., Block 30 sets LOGIC SWITCH 2 of Room 1 to a "set" condition; consequently, entries will not be

---

* See footnote on page 69.

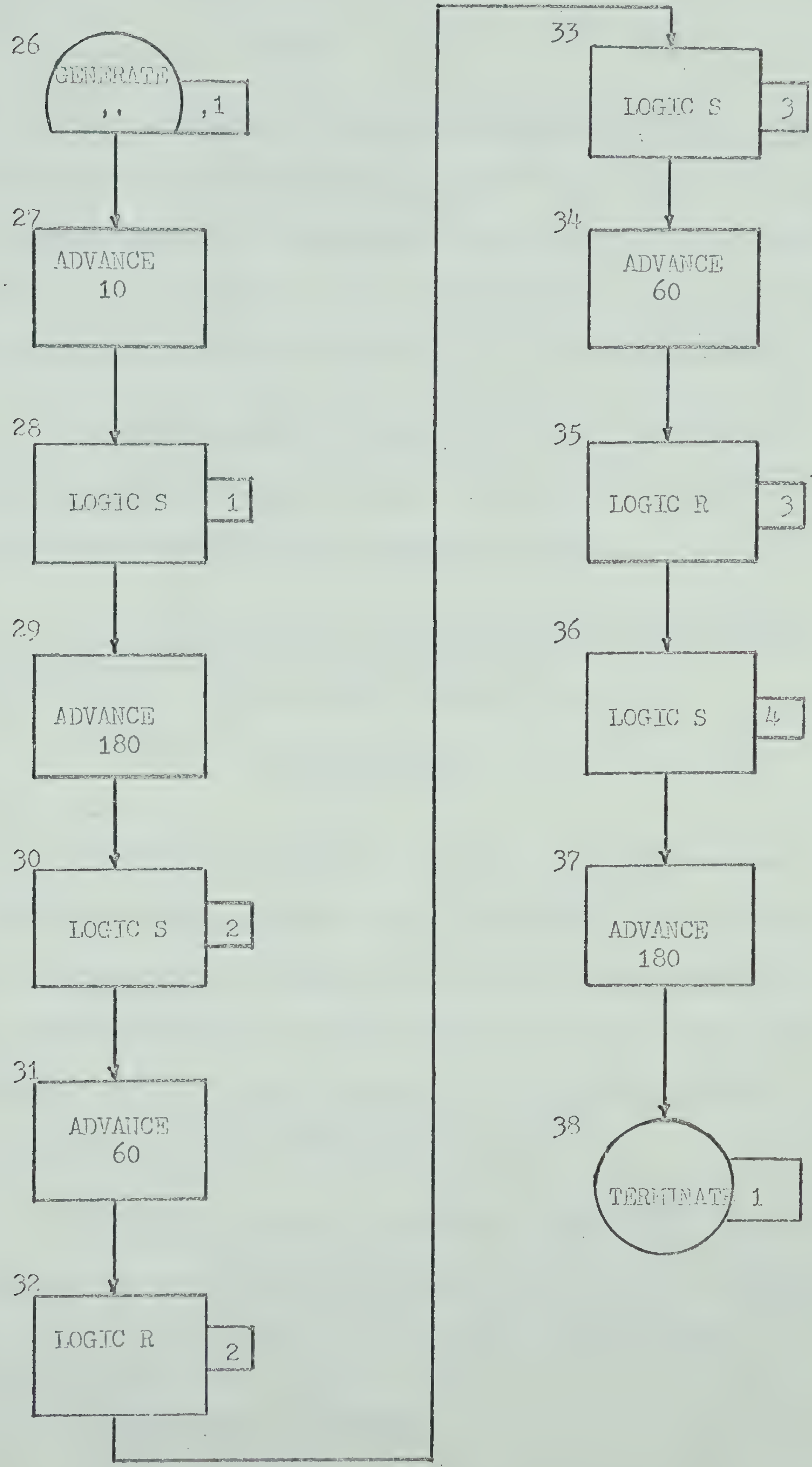


FIGURE 15. BLOCK DIAGRAM FOR CLOCK CONTROL

permitted. At this point, Room 1's technician goes for lunch. After 60 minutes (Block 31) the LOGIC SWITCH is again "reset" (Block 32), and entries are permitted again. When Room 1's technician returns, Room 7's technician goes out immediately for 60 minutes (12:00 p.m. to 1:00 p.m.). Similar controls are executed by Blocks 33, 34, and 35 for Room 7.

The LOGIC SWITCH 4 of Block 36 is "set" at 1:00 p.m. and the Boonlean variable TESTed by Room 2 should give a result of one.* In other words, this operation opens Room 2 at 1:00 p.m.

Block 38 removes all transactions after 180 minutes** has elapsed (Block 37). The department closes at 4:00 p.m.

PROGRAM INPUT

From the block diagram, one card is punched for each block. This set of cards, together with a few control and definition cards, are the input to the program. The cards are used to set up the simulation model and they are executed on the IBM 360/67. The present model simulates arrivals for only one day. It is assumed that the random number generator of the GPSS/360 is perfect.

The input is shown in Appendix A. The block numbers do not coincide with the block diagram explained above but the cards are in the same order. Comments are provided from column 31 onwards.

---

* 2 BVARIABLE LS4*FNU2

<u>Explanation</u>: Boonlean variable of Room 2 will produce a result of one only when LOGIC SWITCH 4 is in a set condition and Room 2 is not in use.

** 1:00 p.m. to 4:00 p.m. = 180 minutes.

The symbols used are similar to those in Figure 6.

PROGRAM OUTPUT AND MODEL VALIDATION

The results of a one-day run is shown in Appendix B.

The assembly phase, as the term implies, assembles the program and uses block numbers for cross reference instead of symbols.

The model automatically prints the number of patients that have been transacted during the day and indicates the number of transactions presently delayed in each instruction.

The model also provides information automatically for the followings:

(1) Facility Output

(2) Storage Output

(3) Savevalue Output

(4) Queue Output

The following information were requested:

(1) Table 11 - arrival pattern

(2) Table 12 - pattern of Queue 21

The model does not represent the real system in every detail but the important characteristics are considered. The output shows that the simulated data proved to be quite similar to the real system. The mean waiting time before examination from the two-week sample is 25.828 minutes with a standard deviation of 26.444 minutes.

The simulated data shows that, on the average, patients wait for 29.000 minutes with a standard deviation of 27.687 minutes. The mean is quite close.

EVALUATION OF ALTERNATIVE PERFORMANCE LEVEL

The waiting time before x-ray examination (variable 2 of page 23) changes if we change the service capacity (parameter 5). Therefore, the alternative performance of variable 2 needs to be evaluated when parameter 5 takes the value of 1 .... i. For this study, i = 5.

Lunch breaks of technicians for different service capacity are assumed to be as follows:

Number of Rooms	Lunch Break
1	11:00 a.m. - 12:00 p.m.
2	11:00 a.m. - 12:00 p.m. 12:00 p.m. - 1:00 p.m.
3	11:00 a.m. - 12:00 p.m. 1 technician; 12:00 p.m. - 1:00 p.m. 2 technicians.
4	11:00 a.m. - 12:00 p.m. 2 technicians; 12:00 p.m. - 1:00 p.m. 2 technicians.
5	11:00 a.m. - 12:00 p.m. 3 technicians; 12:00 p.m. - 1:00 p.m. 2 technicians.

CHAPTER VI

FINDINGS

The criteria set forth in Chapter II, Statement of the Problem, are satisfied if the department has three x-ray rooms operating for eight hours per day. With three rooms, the average waiting time before examination is 6 minutes and 77.9 percent of all patients wait for 10 minutes or less. The technician/room is utilized for 77.4 percent of the time based on the average of the three rooms. The remainder 22.6 percent is considered as idle time. It has been pointed out that the technician is not totally unproductive during such idle time. It seems that three rooms produce a reasonable balance between patients' waiting time and technicians' idle time.

It is uncertain whether this is the best provision of x-ray rooms in comparison with the alternatives. The printout of the average waiting time before examination and the average utilization of the x-ray room/technician for the alternatives are as follows:

No. of Rooms	Ave. Room Utilization	Idle Time of Room/Technician	Ave. Patient Waiting Time (nearest minute)
1	.873	.127	152
2	.868	.132	39
3	.774	.226	6
4	.591	.409	3
5	.516	.484	2

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]

The provision of four rooms instead of three decreases patients' waiting time for only 3 minutes. However, if two rooms were provided, patients have to wait an unreasonable length of time. The provision of four rooms also increases technicians' idle time quite considerably.

On account of the fact that a patient has to spend time for the x-ray examination, for the film to process, etc., it seems that with three rooms a typical patient has to spend about half an hour at the department. A typical patient may be defined as one who does not need a re-x-ray and who does not need portering service.

With the present arrangement of two rooms in the morning and three rooms in the afternoon, the average waiting time before examination is almost 30 minutes. The waiting time is a great difference in comparison to a 3-room situation. The likely reason is that patients wait considerably longer in the morning (on an average, about 40 minutes) and afternoon arrivals cannot be served quickly when the morning backlogs are not cleared.

BIBLIOGRAPHY

Ashworth, W. J. "Functional Studies in Hospitals and Particularly in X-ray Departments." Radiography, XXVII (May, 1961), 131-41.

Ashworth, W. J. "Radiology - Departmental Management." Radiography, XXIV (November, 1968), 243-52.

Bailey, N. T. J. "A Study of Queues and Appointment Systems in Hospital Outpatient Departments, with Special Reference to Waiting Time." Journal of the Royal Statistical Society, XIV(B) (1952), 185-99.

Bridgman, C. F. "To Improve Your Radiographic Facilities, Know How to Get Motion Economy." Hospital Management, LXXVI (October, 1953), 47-8.

Copestake, G. G. "Planning Large X-ray Departments." Canadian Hospital, XLIV (January, 1967), 37-40.

Fetter, R. B. and Thompson, J. A. "Patients' Waiting Time and Doctors' Idle Time in the Outpatient Setting." Health Service Research, I (1966), 66-90.

Fetter, R. B. and Thompson, J. D. "The Simulation of Hospital System." Operations Research, XIII (Sept. - Oct., 1965), 689-711.

Fordham, G. L. "Mechancial Documentation Applied to an X-ray Department." Radiography, XXXIV (April, 1968), 83-86.

Garland, L. H. "Radiologic Services," Modern Concepts of Hospital Administration, ed. J. K. Owen, 307-19. Philadelphia: W. B. Sanders Company, 1962.

General Purpose Simulation System/360, User's Manual. New York: International Business Machine Corporation, 1967.

Graham, S. "Riverside's X-ray Department Uses Advanced Methods to Speed Operation." Hospital Administration In Canada, X (February, 1968), 26-8.

Hasen, E. and Snider, R. L. "Scheduling System Shows Way to Expand X-ray Productivity 30 Per Cent." Modern Hospital, CII (April, 1964), 110-12.

High, E. G. "Administration and X-ray Service." Hospital Progress, XLVI (May, 1965), 126-28, 132, 136-44.

Hillier, F. S. and Lieberman, G. T. Introduction to Operations Research. San Fransico: Holden Day, Inc., 1967.

Hodges, F. J., Lampe, I., and Holt, J. F. Radiology For Medical Students. 4th ed., Chicago Year Book Medical Publishers, Inc., 1965.

Jackson, R. R. P. "Design of an Appointment System." Operational Research Quarterly, XV (September, 1964), 219-24.

Jacobi, C. A., and Paris, D. Q. X-ray Technology. 3rd ed., Saint Louis: The C. V. Mosby Company. 1964.

Kanon, D. "Scheduling System for X-rays Prevents Overtaxing of Facilities." Hospitals, XLI (January, 1967), 87-89.

Katz, J. H. "Simulation of Outpatient Appointment Systems." Communications of The Association For Computing Machinery, XII (April, 1969), 215-22.

King, S. S., and Markewitz, R. "How a Methods Study Exposed an X-ray Problem." Hospitals, XXII (September, 1958), 75-78.

McLeod, J. (ed.). Simulation. New York: McGraw-Hill Book Company, 1968.

Mize, J. H., and Cox, J. G. Essentials of Simulation. Englewood Cliffs, N.J.: Prentice-Hall, Inc., 1968.

Racie, E. M. R. "X-ray Administration." Hospital Management, XC (July, 1960), 104, 106.

Roberts, R. A. "Planning of X-ray Departments in Relation to Other Departments in a Hospital." Radiography, XXII (April, 1956), 78-81.

Smalley, H. E. and Freeman, J. R. (ed.). Hospital Industrial Engineering. New York: Reinhold Publishing Corp., 1966.

Staggs, J. E. "X-ray Service Improved Through Better Control of Records." Hospital Management, CV (June, 1968), 39, 42.

Starkweather, D. B. and Mahoney, G. T. "Practical Economy in the Radiology Department." Hospital Management, XCVI (August, 1963), 75-80.

Thompson, J. B., Avant, O. W., and Spiker, E. D. "How Queuing Theory Works for the Hospital." Modern Hospital, XCIV (March, 1960), 75-80.

Towards A Clearer View - The Organization of Diagnostic X-ray Departments. Nuffield Provincial Hospitals Trust. London: Oxford University Press, 1962.

Welch, J. D. and Bailey, N. T. J. "Appointment Systems in Hospital Outpatient Departments." Lancet, (May, 1952), 1105-1108.

White, M. J. B. and Pike, M. C. "Appointment Systems in Outpatients' Clinics and the Effect of Patients' Unpunctuality." Medical Care, III (may - June, 1964), 133-145.

Whitson, C. W. "An Analysis of the Problems of Scheduling Surgery." Hospital Management, XCIX (May, 1965), 45-49.

Woods, Gordon & Company. "Survey of Clerical Procedures," Vancouver, 1965. (Mimeographed.)

Wren, G. R. "Re-examine X-ray Facilities with Eye to Improve Use." Hospital Management, LXXII (Oct., 1951), 126, 128, 134.

APPENDIX A

PROGRAM INPUT

```
BLOCK
NUMBER  *LOC   OPERATION  A,B,C,D,E,F,G                    COMMENTS
               SIMULATE
        *   INTERARRIVAL TIME DISTRIBUTION
         ARRIV FUNCTION    RN1,C[illegible]
        0,0/.127[illegible],1/.2359,2/.[illegible]176,3/.3[illegible]17,4/.4577,5/.5154,6/.5670,7
        .6[illegible],8/.6[illegible],9/.[illegible],10/.72[illegible],11/.7537,12/.7855,13
        .81[illegible],14/.[illegible]49,15/.[illegible],16/.8721,17/.[illegible],18/.[illegible],19
        .91[illegible],20/.9[illegible],21/.[illegible]31,22/.94[illegible],23/.9547,24/.9[illegible],25
        .9[illegible],26/.97[illegible],27/.9755,28/.98[illegible],29/.9877,30/.[illegible],31/.9959,32
        *   SERVICE TIME DISTRIBUTION
         SERVE FUNCTION    RN1,C29
        .0000,2.22/.0[illegible],3.33/.0[illegible],4.44/.0374,5.55/.0841,6.66/.1462,7.77
        .2225,8.88/.[illegible],10.00/.4129,11.11/.5115,12.22/.5940,13.33/.6599,14.44
        .7131,15.55/.7[illegible],16.66/.7913,17.77/.8190,18.88/.8418,20.00/.8590,21.11
        .8755,22.22/.8[illegible],23.33/.9[illegible],24.44/.9131,25.55/.9261,26.66/.9397,27.77
        .9[illegible],28.88/.9[illegible],30.00/.9786,31.11/.9901,32.22/1.0000,33.33
        *   WAITING TIME DIST. FOR BERTH
         [illegible] FUNCTION    RN1,D24
        .1427,1/.1713,3/.1[illegible],4/.2570,5/.2856,6/.3427,7
        .4282,8/.4519,9/.4[illegible],10/.5141,11/.5427,12/.5713,13
        .59[illegible],14/.6[illegible],16/.6856,17/.7427,18/.7998,19/.8284,20
        .8570,21/.8856,23/.9142,24/.9[illegible],25/.9714,26/1.0,28
         11      TABLE       [illegible],0,2,100
         12      QTABLE      21,0,2,200
         [illegible] STORAGE 26            WAITING ROOM CAPACITY
         1       BVARIABLE   LS2*FNU1      ROOM 1=OPEN + NOT UTILIZE
         7       BVARIABLE   LS3*FNU7      ROOM 7=OPEN + NOT UTILIZE
         2       BVARIABLE   LS4*FNU2      ROOM 2=OPEN + NOT UTILIZE
```

```
      *
      *  CLOCK CONTROL
      *
 1          GENERATE    ,,,1           CLOCK TRANSACTION
 2          ADVANCE     10             10 MINS. FOR EARLY ARRIVALS
 3          LOGIC S     1              DEPT. OPENS AT 8.00 A.M
 4          ADVANCE     180            SERVE PATIENTS-8.00 A.M TO 11.00 A.M
 5          LOGIC S     2              ROOM 1 CLOSES-11.00 A.M
 6          ADVANCE     60             ROOM 1 TECHNICIAN TO LUNCH=1 HR.
 7          LOGIC R     2              ROOM 1 OPENS-12.00 P.M
 8          LOGIC S     3              ROOM 7 CLOSES-12.00 P.M
 9          ADVANCE     60             ROOM 7 TECHNICIAN TO LUNCH=1 HR.
10          LOGIC R     3              ROOM 7 OPENS-1.00 P.M
11          LOGIC S     4              ROOM 2 OPENS-1.00 P.M
12          ADVANCE     180            SERVE PATIENTS-1.00 P.M TO 4.00 P.M
13          TERMINATE   1
      *
      *  OPERATIONS OF THE X-RAY DEPT.
      *
14          GENERATE    1,FN$ARRIV     CREATE ARRIVALS-CONTROL BY CLOCK
15          TABULATE    11             TABULATE ARRIVALS
16          GATE LR     1,*+2          CONTROL OF EARLY ARRIVALS
17          SAVEVALUE   1+,1           RECORD ARRIVALS FROM 7.50-8.00 A.M
18          ENTER       WROOM          PATIENTS TO WAITING ROOM
19          TRANSFER    .254,NEM,EMG   TEST IF PN(TH) PATIENT IS EMG.
20    EMG   PRIORITY    2              IF EMG., ASSIGN PRIORITY 2
21    NEM   QUEUE       21             IF NEM., WAIT AT WAITING RM (QUEUE 21)
22          GATE LS     1              CONTROL FOR OPENING DEPT. AT 8.00 A.M
23          TRANSFER    ALL,24,54,15   ALLOCATE PATIENTS TO X-RAY ROOMS
      *
      *  ROOM 1
      *
24          TEST E      BV1,1          ENTER RM. 1 IF BVARIABLE 1=1
25          SEIZE       1              PATIENT OCCUPIES ROOM 1
26          LEAVE       WROOM          PATIENT LEAVES WAITING ROOM
27          DEPART      21             PATIENT LEAVES QUEUE 21
```

```
28          ADVANCE    1,FN$SERVE   TIME IN RM. 1 = TOTIME(PN)
29          RELEASE    1            PATIENT LEAVES ROOM 1
30          ENTER      WROOM        TO WAITING ROOM AFTER X-RAY
31          ADVANCE    8            FILM PROCESSING TIME=PT(PN)=8 MIN,
32          TRANSFER   ,.308,QGD,QBD TEST WHETHER QUALITY IS QGD OR QBD
33    QBD   PRIORITY   1,BUFFER     IF QBD,, ASSIGN PRIORITY 1
34          TRANSFER   ,NEW         RE-X-RAY NEEDED, TO QUEUE 21
35    QGD   TRANSFER   .309,NPT,POT IF QGD, TEST IF PORTER NEEDED
36    POT   ADVANCE    1,FN$PORTR   WAITING TIME FOR PORTER=TPRT(PN)
37    NPT   LEAVE      WROOM        IF NPT, LEAVE WAITING ROOM
38          TERMINATE
*
*   ROOM 7
*
39          TEST E     BV7,1        OPERATION OF ROOM 7
40          SEIZE      7            IS THE SAME
41          LEAVE      WROOM        AS ROOM 1
42          DEPART     21
43          ADVANCE    1,FN$SERVE
44          RELEASE    7
45          ENTER      WROOM
46          ADVANCE    8
47          TRANSFER   .308,QGD7,QBD7
48    QBD7  PRIORITY   1,BUFFER
49          TRANSFER   ,NEW
50    QGD7  TRANSFER   .309,NPT7,POT7
51    POT7  ADVANCE    1,FN$PORTR
52    NPT7  LEAVE      WROOM
53          TERMINATE
*
*   ROOM 2
*
54          TEST E     BV2,1        OPERATION OF ROOM 2 IS THE SAME
55          SEIZE      2            AS ROOMS 1 OR 7. STARTS AT 1.00 P.M
56          LEAVE      WROOM
57          DEPART     21
```

```
58               ADVANCE     1,FN$SERVE
59               RELEASE     2
60               ENTER       [illegible]
61               ADVANCE     8
62               TRANSFER    .308,QGD2,QBD2
63        QBD2   PRIORITY    1,BUFFER
64               TRANSFER    ,NEM
65        QGD2   TRANSFER    .309,NPT2,PDT2
66        PDT2   ADVANCE     1,FN$PORTR
67        NPT2   LEAVE       [illegible]
68               TERMINATE
                 START       1
                 REPORT
                 TEXT        THE NUMBER OF ARRIVALS IN FIRST 10 MIN IS
                 TEXT        #X1.2/XXX*
                 OUTPUT
                 END
```

APPENDIX B

PROGRAM OUTPUT

BLOCK NUMBER	SYMBOL	REFERENCES BY CARD NUMBER			
20	FMG	52			
21	NFM	52	70	88	106
37	NPT	71			
67	NPT2	107			
52	NPT7	89			
36	PQT	71			
66	PQT2	107			
51	PQT7	89			
33	QFD	68			
63	QFD2	104			
48	QFD7	86			
25	QGD	68			
65	QGD2	104			
50	QGD7	86			

STORAGE SYMBOLS AND CORRESPONDING NUMBERS

1 WROOM

FUNCTION SYMBOLS AND CORRESPONDING NUMBERS

1 ARRIV
3 ROUTE
2 SERVE

```
*  INTERARRIVAL TIME DISTRIBUTION
 1      FUNCTION   RN1   C33
0          0          .1276     1          .2329     2
.3175      3          .3917     4          .4577     5
.5154      6          .5671     7          .6144     8
.6577      9          .6942     10         .7279     11
.7587      12         .7865     13         .8107     14
.8340      15         .8535     16         .8721     17
.8886      18         .9030     19         .9154     20
.9278      21         .9391     22         .9464     23
.9547      24         .9631     25         .9692     26
.9754      27         .9795     28         .9836     29
.9877      30         .9918     31         .9959     32
*  SERVICE TIME DISTRIBUTION
 2      FUNCTION   RN1   C29
.0000      2.22       .0016     3.33       .0103     4.44
.0374      5.55       .0841     6.66       .1462     7.77
.2229      8.89       .3125     10.00      .4109     11.11
.5115      12.22      .5940     13.33      .6599     14.44
.7131      15.55      .7505     16.66      .7912     17.77
.8190      18.88      .8419     20.00      .8590     21.11
.8725      22.22      .8887     23.33      .9006     24.44
.9131      25.55      .9261     26.66      .9397     27.77
.9528      28.89      .9685     30.00      .9726     31.11
.9891      32.22      1.0000    33.33
*  WAITING TIME DIST. FOR POSTER
 3      FUNCTION   RN1   D24
.1427      1          .1713     3          .1999     4
.2570      5          .2856     6          .3427     7
.4283      8          .4569     9          .4855     10
.5141      11         .5427     12         .5713     13
.5999      14         .6570     16         .6856     17
.7427      18         .7999     19         .8284     20
.8570      21         .8856     23         .9140     24
.9228      25         .9714     26         1.0       28
 11     TABLE      IA     0     2     100
 12     QTABLE     21     0     2     200
 1      STORAGE    20
 1      BVARIABLE  LR2*FNU1
 7      BVARIABLE  LR3*FNU7
 2      BVARIABLE  LS4*FNU2.
```

```
*
*  CLOCK CONTROL
*
 1      GENERATE                            1
 2      ADVANCE      1'
 3      LOGICS       1
 4      ADVANCE      180
 5      LOGICS       2
 6      ADVANCE      [illegible]
 7      LOGICR       2
 8      LOGICS       3
 9      ADVANCE      60
10      LOGICR       3
11      LOGICS       4
12      ADVANCE      180
13      TERMINATE    1
*
*  OPERATIONS OF THE X-RAY DEPT.
*
14      GENERATE     1       FN1
15      TABULATE     11
16      GATE LR      1       19
17      SAVEVALUE    1+      1
18      ENTER        1
19      TRANSFER     .254    21      20
20      PRIORITY     2
21      QUEUE        21
22      GATE LS      1
23      TRANSFER     ALL     24      54      15
*
*  ROOM 1
*
24      TEST E       RV1     1
25      SEIZE        1
26      LEAVE        1
27      DEPART       21
```

```
 28     ADVANCE      1      FN2
 29     RELEASE      1
 30     ENTER        1
 31     ADVANCE      8
 32     TRANSFER     .208   35      33
 33     PRIORITY     1      BUFFER
 34     TRANSFER            21
 35     TRANSFER     .309   37      36
 36     ADVANCE      1      FN3
 37     LEAVE        1
 38     TERMINATE
*
*  ROOM 7
*
 39     TEST E       PV7    1
 40     SEIZE        7
 41     LEAVE        1
 42     DEPART       21
 43     ADVANCE      1      FN2
 44     RELEASE      7
 45     ENTER        1
 46     ADVANCE      8
 47     TRANSFER     .208   50      48
 48     PRIORITY     1      BUFFER
 49     TRANSFER            21
 50     TRANSFER     .309   52      51
 51     ADVANCE      1      FN3
 52     LEAVE        1
 53     TERMINATE
*
*  ROOM 2
*
 54     TEST E       PV2    1
 55     SEIZE        2
 56     LEAVE        1
 57     DEPART       21
```

```
58      ADVANCE     1       FN2
59      RELEASE     2
60      ENTER       1
61      ADVANCE     9
62      TRANSFER    .308    65      63
63      PRIORITY    1       BUFFER
64      TRANSFER            21
65      TRANSFER    .309    67      66
66      ADVANCE     1       FN3
67      LEAVE       1
68      TERMINATE
        START       1
THE NUMBER OF ARRIVALS IN FIRST 10 MIN IS
  2
```

RELATIVE CLOCK 491 ABSOLUTE CLOCK 491

BLOCK COUNTS

BLOCK	CURRENT	TOTAL	BLOCK	CURRENT	TOTAL	BLOCK	CURRENT	TOTAL
1	0	1	11	0	1	21	0	87
2	0	1	12	0	1	22	0	87
3	0	1	13	0	1	23	8	87
4	0	1	14	0	68	24	0	31
5	0	1	15	0	68	25	0	31
6	0	1	16	0	68	26	0	31
7	0	1	17	0	2	27	0	31
8	0	1	18	0	68	28	1	31
9	0	1	19	0	68	29	0	30
10	0	1	20	0	14	30	0	30

BLOCK	CURRENT	TOTAL	BLOCK	CURRENT	TOTAL	BLOCK	CURRENT	TOTAL
31	0	30	41	0	36	51	0	3
32	0	30	42	0	36	52	0	27
33	0	9	43	1	36	53	0	27
34	0	0	44	0	35	54	0	12
35	0	21	45	0	35	55	0	12
36	0	6	46	0	35	56	0	12
37	0	21	47	0	35	57	0	12
38	0	21	48	0	8	58	1	12
39	0	36	49	0	9	59	0	11
40	0	36	50	0	27	60	0	11

BLOCK	CURRENT	TOTAL	BLOCK	CURRENT	TOTAL
61	0	11			
62	0	11			
63	0	2			
64	0	2			
65	0	9			
66	1	4			
67	0	8			
68	0	8			

FACILITY	AVERAGE UTILIZATION	NUMBER ENTRIES	AVERAGE TIME/TRAN	SEIZING TRANS. NO.	PREEMPTING TRANS. NO.
1	.861	31	13.645	13	
2	.366	12	15.000	14	
7	.875	36	11.944	9	

STORAGE	CAPACITY	AVERAGE CONTENTS	AVERAGE UTILIZATION	ENTRIES	AVERAGE TIME/TRAN
WROOM	20	6.503	.325	144	22.173

CURRENT CONTENTS	MAXIMUM CONTENTS
9	13

QUEUE	MAXIMUM CONTENTS	AVERAGE CONTENTS	TOTAL ENTRIES	ZERO ENTRIES	PERCENT ZEROS	AVERAGE TIME/TRANS
21	11	4.993	87	1	1.1	28.126

$AVERAGE TIME/TRANS	TABLE NUMBER	CURRENT CONTENTS
28.453	12	8

CONTENTS OF FULLWORD SAVEVALUES (NON-ZERO)

SAVEVALUE NR,	VALUE	NR,	VALUE	NR,	VALUE	NR,	VALUE
1	2						

TABLE 11

ENTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION
67	7,119	6,574

UPPER LIMIT	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER
0	6	8,95	8,9	91,0
2	15	22,38	31,3	68,6
4	14	20,89	52,2	47,7
6	6	8,95	61,1	38,8
8	4	5,97	67,1	32,8
10	3	4,47	71,6	28,3
12	2	2,98	74,6	25,3
14	4	5,97	80,5	19,4
16	3	4,47	85,0	14,9
18	4	5,97	91,0	8,9
20	4	5,97	97,0	2,9
22	2	2,98	100,0	,0

REMAINING FREQUENCIES ARE ALL ZERO

SUM OF ARGUMENTS 477,000 NON-WEIGHTED

MULTIPLE OF MEAN	DEVIATION FROM MEAN
-,000	[illegible]
,281	-,778
,561	-,474
,842	-,170
1,123	,132
1,404	,438
1,685	,742
1,966	1,046
2,247	1,350
2,528	1,655
[illegible]	1,960
3,090	2,263

TABLE 12

ENTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION	SUM OF ARGUMENTS
79	29.000	27.687	2291.000

UPPER LIMIT	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
0	1	1.26	1.2	98.7	-.000	-1.047
2	6	7.59	8.8	91.1	.068	-.975
4	8	10.12	18.9	81.0	.137	-.902
6	5	6.32	25.3	74.6	.206	-.830
8	4	5.06	30.3	69.6	.275	-.758
10	3	3.79	34.1	65.8	.344	-.686
12	3	3.79	37.9	62.0	.413	-.613
14	0	.00	37.9	62.0	.482	-.541
16	3	3.79	41.7	58.2	.551	-.469
18	1	1.26	43.0	56.9	.620	-.397
20	3	3.79	46.8	53.1	.689	-.325
22	1	1.26	48.1	51.8	.758	-.252
24	4	5.06	53.1	46.8	.827	-.180
26	2	2.53	55.6	44.3	.896	-.108
28	0	.00	55.6	44.3	.965	-.036
30	4	5.06	60.7	39.2	1.034	.036
32	0	.00	60.7	39.2	1.103	.108
34	1	1.26	62.0	37.9	1.172	.180
36	4	5.06	67.0	32.9	1.241	.252
38	1	1.26	68.3	31.6	1.310	.325
40	2	2.53	70.8	29.1	1.379	.397
42	0	.00	70.8	29.1	1.448	.469
44	0	.00	70.8	29.1	1.517	.541
46	3	3.79	74.6	25.3	1.586	.613
48	1	1.26	75.9	24.0	1.655	.686
50	6	7.59	83.5	16.4	1.724	.758
52	4	5.06	88.6	11.3	1.793	.830
54	0	.00	88.6	11.3	1.862	.902
56	2	2.53	91.1	8.8	1.931	.975
58	1	1.26	92.4	7.5	2.000	1.047
60	0	.00	92.4	7.5	2.068	1.119
62	2	2.53	94.9	5.0	2.137	1.191

64	0	.00	94.9	5.[illegible]	2.206	1.264
66	0	.00	94.9	5.[illegible]	2.275	1.336
68	0	.00	94.9	5.[illegible]	2.344	1.408
70	0	.00	94.9	5.[illegible]	2.413	1.481
72	0	.00	94.9	5.[illegible]	2.482	1.553
74	0	.00	94.9	5.[illegible]	2.551	1.625
76	1	1.26	96.2	3.7	2.620	1.697
78	0	.00	96.2	3.7	2.689	1.769
80	0	.00	96.2	3.7	2.758	1.841
82	0	.00	96.2	3.7	2.827	1.914
84	0	.00	96.2	3.7	2.896	1.986
86	0	.00	96.2	3.7	2.965	2.058
88	0	.00	96.2	3.7	3.034	2.130
90	0	.00	96.2	3.7	3.103	2.203
92	0	.00	96.2	3.7	3.172	2.275
94	0	.00	96.2	3.7	3.241	2.347
96	0	.00	96.2	3.7	3.310	2.419
98	0	.00	96.2	3.7	3.379	2.492
100	0	.00	96.2	3.7	3.448	2.564
102	0	.00	96.2	3.7	3.517	2.636
104	0	.00	96.2	3.7	3.586	2.708
106	0	.00	96.2	3.7	3.655	2.781
108	0	.00	96.2	3.7	3.724	2.853
110	0	.00	96.2	3.7	3.793	2.925
112	0	.00	96.2	3.7	3.862	2.997
114	0	.00	96.2	3.7	3.931	3.069
116	1	1.26	97.4	2.5	4.000	3.142
118	0	.00	97.4	2.5	4.068	3.214
120	0	.00	97.4	2.5	4.137	3.286
122	0	.00	97.4	2.5	4.206	3.358
124	0	.00	97.4	2.5	4.275	3.431
126	0	.00	97.4	2.5	4.344	3.503
128	0	.00	97.4	2.5	4.413	3.575
130	1	1.26	98.7	1.2	4.482	3.647
132	0	.00	98.7	1.2	4.551	3.720
134	0	.00	98.7	1.2	4.620	3.792
136	0	.00	98.7	1.2	4.689	3.864
138	1	1.26	100.0	.0	4.758	3.936

REMAINING FREQUENCIES ARE ALL ZERO

```
LOGIC SWITCH - SET (ON) STATUS
SWITCH    NR    N     NR    NR    N     NR    NR    NR    NR    NR    NR    NR    NR    NR
          1     4

    CARDS READ --      468 LINES PRINTED --      0 CARDS PUNCHED --     .49 MINUTES EXECUTION TIME
```